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A MANUAL
OF
THE GEOLOGY OF INDIA AND BURMA

VOLUME III

VIEW DOWN THE SUTLEJ VALLEY FROM CHABA, NORTH OF SIMLA, SHOWING GRAVEL TERRACES.

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A MANUAL

OF

THE GEOLOGY OF INDIA AND BURMA

VOL. III

Compiled from the observations of the Geological Survey of India and from unofficial sources by H. B. MEDLICOTT, W. T. BLANFORD, V. BALL and F. R. MALLET.

Second Edition by R. D. OLDHAM

Third Edition, revised and largely rewritten

by SIR EDWIN H. PASCOE, Kt.,
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formerly Director, Geological Survey of India.

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FOREWORD

The First Volume of this Manual was published in 1950, but various unavoidable and unforeseen difficulties have prevented the publication of the subsequent volumes in time. The Second Volume was published in 1960; the third and last volume is now being presented. The manuscripts of the Index prepared by Sir Edwin Pascoe could not be traced and it has not been possible to prepare the same afresh. It is, however, needless to stress that these three volumes would serve as valuable works of reference regarding the geology of India and adjoining countries.

After the manuscript of the Manual was completed by the late Sir Edwin Pascoe, the geology of many parts of India has been revised on more modern maps and on aerial photographs, several investigations have been carried out afresh and new mineral bearing zones have been discovered. No attempt has, however, been made to incorporate the results of these later investigations in the present edition which is essentially the same as was originally written up by the late Sir Edwin Pascoe.

B. C. ROY,
DIRECTOR GENERAL,
Geological Survey of India.

CALCUTTA,

The 15th July, 1962.

PREFACE TO THE THIRD EDITION.

The First Edition of this Manual was issued in 1879, and the Second fourteen years later in 1893. The latter was compiled before the microscope came into prominent use for petrological purposes, and no edition has appeared since. The present edition, long overdue, embodies more than fifty years' additional work, not only by the largely increased staff of the Geological Survey of India but also by many unofficial investigators. The colossal size of the task of co-ordinating all this accumulation of work must be my plea for some at least of the shortcomings and omissions that seem almost inevitable.

Certain portions of the text of the Second Edition have been incorporated with but slight modification, but the bulk of the present edition is entirely new. An attempt has been made to render it more a work of reference than a students' text-book, since the latter is available in the form of Mr. D. N. Wadia's excellent and well-known publication. An attempt to cater for the local geologist in India has played its part in swelling the volume of the work. This edition of the Manual makes no pretence of being more than it is—a compilation of the writings, mostly published, of a large band of workers, to all of which it would be a pleasure to pay tribute by name, did space permit. One of the effects of a wise system of Mining Regulations has been to encourage unofficial geological investigation in India and Burma, and oil companies and companies engaged in the exploitation of other minerals have for a long time past employed their own geological staffs for exploratory purposes, and many valuable papers have issued from the pens of such men as Mr. E. S. Pinfold, Mr. P. Evans, Dr. F. G. Percival and Dr. A. W. G. Bleeck. In addition, a large number of academical workers have visited India and Burma from time to time, some of them for lengthy periods, and have made contributions to our knowledge of the subject in the Memoirs and Records of the Geological Survey of India, in the Transactions of the Mining and Geological Institute of India, and in other publications too numerous to mention. Dr. W. F. Smeeth and his colleagues in the Mysore Geological Department have in many ways modified our conceptions of the Archaean of Southern India. Dr. L. Dudley Stamp, at one time Professor in Rangoon University, has contributed many original ideas on the Tertiary geology of Burma. Colonel L. M. Davies, by combining geological field-work with his military duties, has added considerably to our knowledge of the Eocene rocks of the North-West-Frontier. Numerous eminent American authorities, among whom may be mentioned Dr. W. D. Matthew, Dr. H. de Terra, Dr. G. E. Lewis, Dr. Barnum Brown and Dr. Colbert, together with a French geologist, M. L'Abbé T. de Chardin of the Geological Survey of China, have made the study of Siwalik vertebrates and stratigraphy peculiarly their own; their numerous published contributions to this subject have been freely consulted and used. The Italian expeditions to

Kashmir and the Karakoram, and the various climbing parties, especially those to Mount Everest, have discovered many new facts and produced many new suggestions concerning the Extra-peninsular regions. One of the latest of these is a memoir by Messrs. Arnold Heim and Gansser, containing some important deductions connected with Himalayan stratigraphy. Mr. Pinfold's prolonged work on the oilfields of the Punjab has done much to assist in our correlation of the Eocene. Mr. P. Evans' survey of Assam has laid the foundations of a proper consecutive classification of the Tertiaries in that somewhat neglected province ; only those who have suffered its enervating and not too healthy climate, the denseness of its jungles and the frequent dearth of exposures, can appraise to the full the value of such an accomplishment. Among the many distinguished palaeontologists who have from time to time lent us their valuable assistance, the two most prominent names are those of Dr. Cowper Reed of Cambridge and Dr. L. F. Spath of the Natural History Museum, South Kensington. The former has been associated with the Geological Survey of India for so many years and has contributed so many valuable memoirs to the " Palaeontologia Indica ", that he is justly esteemed by all officers of the department as the *doyen* of Indian palaeontology. Dr. Spath's monumental works on the ammonite faunas of India have also left us in his debt to an extent which it would be difficult to exaggerate. In addition, we may pay grateful tribute to such well-known names as J. W. Gregory, F. L. Kitchin, P. Martin Duncan, W. P. Sladen, C. Diener, E. von Mojsisovics, A. Bittner, V. Uhlig, K. Redlich, R. Zeiller, Sir Albert Seward, Sir Arthur Smith Woodward, B. Sahni, Miss E. Healy, M. Cossmann, G. Pissaro, S. S. Buckman, H. Douville, E. Spengler, C. Forster Cooper, L. R. Cox, Miss H. M. Muir-Wood, W. L. F. Nuttall, C. A. Matley, L. Rama Rao, J. Pia, J. A. Douglas and W. B. R. King.

To my colleagues of the Geological Survey of India I am indebted, not only for the innumerable published papers which have furnished the foundations of this book, but for more direct help in criticism and suggestions regarding the text itself. Especially have I to thank Dr. J. Coggin Brown, whose unstinted assistance has done much to improve the accuracy and complete the scope of the chapters on Burma: his unrivalled knowledge of the geology of that former province of the Indian Empire has been generously and unreservedly placed at my disposal. The chapters on the Upper Tertiary are greatly the better for the expert scrutiny of my colleague Dr. G. E. Pilgrim, to whose ungrudging help I gratefully testify. To Sir Lewis Fermor, Dr. A. M. Heron, Dr. J. A. Dunn and Dr. W. D. West I am deeply indebted for opinions and criticism concerning the chapters on the Archaean. To Dr. W. D. West, and Messrs. J. B. Auden and D. N. Wadia I am grateful for help in connection with Himalayan stratigraphy and tectonics. I have also received much assistance from Mr. E. R. Gee upon the stratigraphy of the Salt Range, from Dr. H. Croonkshank upon the Deccan Trap, and from Dr. M. R. Sahni concentrating fossil nomenclature. Dr. B. Sahni's publications on Gondwana plants have formed the basis of much of the text on this

subject. Dr. J. A. Dunn has been kind enough to revise the chapter on the Archaean of Singhbhum in the light of some very recent discoveries of his own—discoveries which have removed some deep misgivings in my own mind concerning some of the statements previously published regarding the rock relationships of that region. To Dr. A. L. Coulson I am indebted for suggestions regarding the chapters on Rajputana and the section on the Cuddapah rocks of Madras. To Dr. M S. Krishnan I owe acknowledgement for general help as well as for suggestions in connection with the geology of Gangpur and neighbouring parts. I thankfully acknowledge assistance from Dr. L. F. Spath of the Natural History Museum, South Kensington, regarding the ammonites and classification of the Lower Trias, and from Colonel L. M. Davies for corrections and suggestions concerning the text dealing with the Palaeocene and Eocene. Finally, I must not omit to acknowledge the constant help derived from Sir Thomas Holland's memoir on Indian Geological Terminology (Mem. LI, Pt. 1, 1928), which with few exceptions has been followed, and from Mr. La Touche's various indexes.

In a book of this kind it is sometimes difficult to decide to what extent it is justifiable to allow one's views to outweigh those of others. Two alternative methods of procedure present themselves in the very numerous cases where doubt exists as to the precise conclusion to be drawn from the available evidence. On the one hand, the author can select the view which in his judgment deserves support and adopt it, with or without a word of caution to the reader: on the other hand, he may choose to lay the facts as fully as space permits before the reader and leave him to make his own conclusions. The former is the one adopted by most text-books, since condensation demands it, the result often being a too definite picture which has earned the term of "text-booky". At the same time, the second method leads to greater prolixity and to a less connected and less readable story. In this work I have attempted a compromise between the two, reverting more often perhaps than the majority of text-book writers to the second method.

For the constant repetitions in the text I feel no apology is necessary. They have been allowed to remain for what is often referred to in correspondence of an official nature as "easy reference" Chapter headings have given some trouble but I have chosen the terminology of the European sequence even when the correlation is doubtful or not completely dimensional, rather than the use of local names which would mean nothing to readers unacquainted with Indian geological formations. The use of capital letters will more or less explain itself. As examples, "Deccan Trap", so written, is a suite of rocks including ashes and other forms of volcanic material as well as inter-trappean sedimentaries belonging to that suite. "Deccan Trap" is a trap rock belonging to the Deccan Trap suite. "Berach granite" is a Granite found in the Berach river. "Bundelkhand Granite" is a granite suite with a definite systematic position.

To facilitate their location, the latitude and longitude of all lesser-known places will be found after their names in the index at the end of the book. The spelling of names, always a difficulty in countries using an alphabet different from that employed by most European nations, is in nearly all cases that adopted as a standard by modern official gazetteers; as regards place names not mentioned in those publications, the spelling used is that on the latest maps of the Survey of India where these are available. Where advisable, obsolete or alternative spelling are given in brackets. Where an Indian place name has been used to distinguish a geological formation, it has been the custom of the Geological Survey of India to adopt the spelling used by the donor of the name to the formation, whether it conforms to the gazetteer spelling or not. This leads sometimes to different ways of spelling the same word but, although the artificiality of such a convention grates somewhat on the senses and although the risk of ambiguity is not entirely removed by its use, the practice has been followed in this work, in order to avoid what might result in still worse confusion. The spelling of the names of geological subdivisions has, in fact, in nearly all cases been that adopted in Sir Thomas Holland's "Indian Geological Terminology", published as Part I, Volume LI, of the Memoirs of the Geological Survey of India.

The geological map accompanying this text has been compiled, with a few corrections, from the fifth edition of the 32-mile map published by the Geological Survey of India in 1928. The preparation of the text-figures and plates has been kindly superintended by Dr. Coulson and later by Dr. West and Dr. P. K. Ghosh to whom I am further indebted for this assistance as well as for much laborious work connected with the printing.

Earthquakes have been discussed in so far as they throw light on tectonic problems. Mineral springs, of which India can boast a large number, have received brief attention, but a description of Indian meteorites, of which an unusually fine collection may be found in the Indian Museum in Calcutta, has been omitted as being outside the terms of reference.

I have taken the liberty of using the words "mylonise" and "mylonisation" instead of mylonitise and mylonitisation, on the grounds that the noun mylonite is subordinate to the verb expressing the process which produced it.

EDWIN H. PASCOE,

"Fallows Green House",

Harpenden.

27th January, 1939.

The war of 1939 commenced when the work was nearing completion and had reached the revision stage. Final revision has, in consequence, been carried out under great difficulties. In spite of the fact that more than half of the book had been set up in type when Japan entered the war, its publication had to be postponed on account of paper shortage. The type—2½ tons of metal—was broken and melted for munitions purposes. The evacuation of libraries from London, difficulties in travelling facilities and other factors resulting from war conditions have made it impossible to bring the text completely up to date; nevertheless, some additions and a few modifications have been attempted.

EDWIN H. PASCOE,

"Fallows Green House",

Harpenden.

19th August, 1944.

I am sincerely grateful to the Burmah Oil Co., and more specifically to their Chief Geologist, Mr. P. Evans, for much valuable assistance in bringing up to date the Tertiary portion of the geological map published with this work.

EDWIN H. PASCOE,

"St. Nicholas' Lodge",

Harpenden.

12th February, 1949.

THE LATE SIR EDWIN PASCOE

It is with great regret that I have to record the death of Sir Edwin Pascoe on the 7th July, 1949 before the first volume of this work could be issued from the Press.

Sir Edwin began the task of writing the third edition of the Manual in 1933. After devoting seven years to the work, he finally submitted the manuscript of the three volumes at the end of 1939. Unfortunately the extreme shortage of paper in India during the war made it impossible to print even the first volume, although it had been set up in type. The type was distributed and it was not until the end of 1945 that the press could once again take up the work. In the interval Sir Edwin thoroughly revised the text of volumes I and II, corrected all the proofs of volume I, and had completed the correction of the galley proofs of volume II when he was taken seriously ill.

Volume III, still in manuscript, was only partly revised. It is considered, however, that it will be best to publish it as he left it, and it will be sent to the press without further revision. Volume IV, consisting of general and geographical indexes, was started by Sir Edwin, but no trace of it could be found after his death.

Though Sir Edwin did not live to see the publication of his great work, it will long remain a testimony to the industry and scholarship that he devoted to its making over a period of 16 years.

W. D. WEST,

DIRECTOR,
Geological Survey of India.

CALCUTTA,

The 28th October, 1949.

LIST OF ABBREVIATIONS.

Mem.—Memoirs of the Geological Survey of India.

Rec.—Records of the Geological Survey of India.

J.A.S.B.—Journal of the Asiatic Society of Bengal.

Q.J.G.S.—Quarterly Journal of the Geological Society of London.

Man. 2nd Edit.—Manual of the Geology of India, Second Edition, 1893.

Gen. Rep.—General Report of the Geological Survey of India.

Ann. Rep.—Annual Report of the Geological Survey of India.

Pal. Ind. Ser. and New Ser.—Palaeontologia Indica, Series and New Series.

Ann. Mag. Nat. Hist.—The Annals and Magazine of Natural History.

Bull. Geol. Soc. Amer.—Bulletin of the Geological Society of America.

Trans. Min. Geol. Inst. Ind.—Transactions of the Mining and Geological Institute of India (later Mining, Geological and Metallurgical Institute of India).

Trans. Roy. Soc. Ed.—Transactions of the Royal Society of Edinburgh.

Bull. Amer. Mus. Nat. Hist.—Bulletin of the American Museum of Natural History.

Journ. Inst. Petrol. Techn.—The Journal of the Institution of Petroleum Technologists (later, the Institute of Petroleum).

ILLUSTRATIONS.

PLATES.

Frontispiece : View down the Sutlej Valley from Chaba, North of Simla, showing Gravel Terraces.

Geological map of India : In pocket, back cover (on the scale 1":96 miles).

Facing page.

Inter-Trappean Fossils (A). 1378

(1) *Bullinus (Physa) prinsepii* Sow. (×1).
Q. J. G. S., Vol. XVI, Pl. V, fig. 23a (1860).

(2) *Cerithium stoddardi* Hisl. (×1).
Q. J. G. S., Vol. XVI, Pl. VIII, fig. 35 (1860).

(3) *Lymnaea subulata Sow.* (×1).
Q. J. G. S., Vol. XVI, Pl. V, fig. 19 (1860).

(4) *Turritella praelonga* Hisl. (×1).
Q. J. G. S., Vol. XVI, Pl. VIII, fig. 37a (1860).

(5) *Viviparus normalis* Hisl. (×1).
Q. J. G. S., Vol. XVI, Pl. V, fig. 2b (1860).

(6) *Natica stoddardi* Hisl. (×1).
Q. J. G. S., Vol. XVI, Pl. VIII, fig. 31 (1860).

(7) *Paludina deccanensis* Sow. (×1).
Trans. Geol. Soc., 2nd Ser., Vol. V, Pl. XLVII, fig. 22 (1840).

(8) *Unio deccanensis* Sow. (×1).
Trans. Geol. Soc., 2nd Ser., Vol. V, Pl. XLVII, fig. 5 (1840)

Inter-Trappean Fossils (B). 1379

(1) *Oxyglossus pussilus* Owen (×2).
Mem., Vol. VI, Pl. IX, fig. 1 (1867).

(2) (*a*) (*b*) (c) *Cypris subglobosa* Sow. (magnified).
Trans. Geol. Soc. 2nd Ser., Vol. V, Pl. XLVII. fig. 3 (1840).

(3) Enigmocarpon parijai Sahni (×4).
Jour. Pal. Soc. Ind., Vol. I, Pl. 24 (1956).

(4) (*a*) (b) (c) *Chara malcolmsonii* Sow. (magnified).
Trans. Geol. Soc., 2nd Ser., Vol. V, Pl. XLVII, fig. 1. (1840).

(5) Nandid fish scale (×18).
Rec. Vol. 73, pt. 3, Pl. XVII, fig. 2 (1938).

ILLUSTRATIONS—*contd.*

Facing page.

Palaeocene & Eocene Fossils (A). 1484

(1) *Nautilus subfleuriausianus* d'Arch. (×½).
Pal. Ind. New Ser., Vol. X, Mem. 4, Pl. I, fig. 3 (1928).

(2) *Ostraea talpur* Vred. (×½).
Pal. Ind. New Ser., Vol. X, Mem. 4, Pl. IX, fig. 2a (1928).

(3) *Calyptrophorus indicus* Coss. & Piss. (×1).
Pal. Ind. New Ser., Vol. III, Mem. 1, Pl. V, fig. 2 (1909).

(4) *Schizaster alveolatus* Dunc. & Slad. (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. XX, fig. 10 (1871-85).

(5) *Ampullina polybathra* Coss. & Piss. (×1).
Pal. Ind. New Ser. Vol. III, Mem. 1, Pl. V, fig. 25 (1909).

(6) *Miscellanea miscella* d'Arch. & Haime, Meridian Section (×22½).
Pal. Ind. New Ser., Vol. XXIV, Mem. 1, Pl. VI, fig. 7 (1937).

(7) *Miscellanea miscella* d'Arch & Haidme, Equatorial Section (×22½).
Pal. Ind. New Ser., Vol. XXIV, Mem. 1, Pl. VI, fig. 8 (1937).

(8) *Nummulites nuttali* Davies (×4).
Pal. Ind. New Ser., Vol. XXIV, Mem. 1, Pl. III, fig. 1 (1937).

Palaeocene & Eicene Fossils (B). 1485

(1) *Gisortia murchisoni* d'Arch. (×1).
Pal. Ind. New Ser., Vol. III, Mem. 1, Pl. IV, fig. 7 (1909).

(2) *Natica adela* Coss. & Piss. (×1).
Pal. Ind. New Ser., Vol. X, Mem. 4, Pl. V, fig. 10 (1928).

(3) *Belosepia incurvata* Coss. & Piss. (×2).
Pal. Ind. New Ser., Vol. III, Mem. 1, Pl. I, fig. 11 (1909).

(4) *Montlivaltia granti* d'Arch & Haime (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 2, Pl. XI, fig. 14 (1871-85).

(5) *Rimella fusoides* d'Arch. (×2).
Pal. Ind. New Ser., Vol. III, Mem. 1, Pl. VII, fig. 46 (1909).

(6) *Dictyoconoides cooki* Carter (×10).
Trans. Roy. Soc. Ed., Vol. 57, pt. II, Pl. I, fig. 9, p. 428 (1934).

(7) *Assilina granulosa* d'Arch (×4).
Pal. Ind. New Ser., Vol. XXIV, Mem. I, Pl. IV, fig. 5 (1937).

(8) *Assilina grauulosa* d'Arch., Meridian Section (×10).
Pal. Ind. New Ser., Vol. XXIV, Mem. I, Pl. IV, fig. 9 (1937).

Oligocene Fossils. 1626

(1) *Montlivaltia vignei* d'Arch. & Haime (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 2, Pl. V, fig. 9 (1871-85).

(2) *Clypeaster profundus* d'Arch & Haime (×2½).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. L, fig. 1 (1871-85).

ILLUSTRATIONS—*contd.*

Facing page.

Oligocene Fossils—*Contd.*

(3) *Cidaris verneuilli* d'Arch. (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. V, fig. 6 (1871-85).

(4) *Temnechinus rousseaui* d'Arch. (×2).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. XXII, fig. 13 (1871-85).

(5) *Coelopleurus forbesi* d'Arch. (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. XLVI, fig. 1 (1871-85).

(6) *Moira primaeva* Dunc. & Slad. (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. XXXV, fig. 1 (1871-85).

(7) *Lepidocyclina didlatata* (Micheloti) (×16).
Mem. de la Soc. Geologique de France, Palaeontologie No. 32, Pl. III, fig. 10 (1904).

(8) (*a*) (*b*) (*c*) *Nummulites intermedius* d'Arch. (×1).
Des Animaux Fossiles Du Groupe Nummulitique De L'Inde, Pl. IV, fig. 8, 8a & 8b (1853).

Lower Miocene Fossils. 1644

(1) *Breynia carinata* d'Arch. & Haime (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. LIV, fig. 5 (1871-85).

(2) *Echinolampus jacquemonti* d'Arch. & Haime (×1).
Pal. Ind. Ser. XIV, Vol. I, pt. 3, Pl. LIII, fig. 1 (1871-85).

(3) *Lepidocyclina tournoueri* Lem. & Douv., Horizontal Section (×18).
Catalogue of Foraminifera, New York.

(4) *Lepidocyclina tournoueri* Lem. & Douv., Vertical Section (×22½)
Catalogue of Foraminifera, New York.

(5) *Orbiculina malabarica* (Carter) (×1).
Ann. Mag. Nat. Hist., 2nd Ser., Vol. XI, Pl. XVI B, fig. 2 (1853).

(6) *Ostraea latimarginata* Vred., Internal View (×1).
Mem., Vol. L, Pl. 24, fig. 2a (1925).

(7) *Turritella angulata* Sow. (×1).
Mem., Vol. L, G. S. I. Type No. 13450, p. 378 (1925).

(8) *Lepidocyclina sumatrensis* (Brady) (×18).
Mem. de la Soc. Geologique de France Palaeontologie No. 32, Pl. I, fig. 14 (1904).

Mud Volcano, Minbu, Burma. 1694

Thrust plane between the Murrees and the Boulder Conglomerate. 1757

Siwalik Fossils (A). 1798

(1) *Sivatherium giganteum* Falc. & Cautl. (×1/13).

(2) *Sivacapra sivalensis* (Lyd.) (1/4).

(3) *Rhinoceros sivalensis* (Falc. & Cautl.) Right upper molar (×2/3).

ILLUSTRATIONS—*contd.*

Facing page.

Siwalik Fossils (A)—*contd.*

(4) *Giraffa sivalensis* (Falc. & Cautl.), Left upper molar (×1).

(5) *Papio subhimalayanus* (H.v.Meyer), Right upper molar (×1).

(6) *Hipparion antilopinum* (Falc. & Cautl.), Left lower molars and premolars (×1).

(7) *Agriotherium palaeindicum* (Lyd.), Right upper molars and premolars (×1).

(8) *Crocuta colvini* (Lyd.), Right upper premolar (×1).

(All figures are reproduced from "Geology of India, 2nd Ed., 1893" by R. D. Oldham, 1st Plate facing page 362).

Siwalik Fossils (B). 1799

(1) *Stegodon ganesa* (Falc. & Cautl.), Cranium (×1/50).

(2) *Stegodon ganesa* (Falc. & Cautl.) (×1/4).

(3) *Elephas hysudricus* (Falc. & Cautl.), Left lower molar (×1/3).

(4) *Mastodon* (*Trilophodon*) *falconeri* (Lyd.), 2nd right lower molar (×1/3).

(5) *Mastodon latidens* Clift. 2nd right upper molar (×1/3).

(6) *Dinotherium giganteum* (*indicum*) (Falc. & Cautl.), Left lower molar (×1/2).

(7) *Sus hysudricus* Falc. & *Cautl.*, Right upper molar (×1).

(All figures are reproduced from "Geology of India, 2nd Ed., 1898" by R. D. Oldham 2nd Plate, facing page 362).

The Central Cone of Barren Islands. 1872

Pleistocene Fossils.

Elephas antiquus (*namadicus*) Cranium, (Falc. & Cautl), (×1/13). 1889

Rec., Vol. XXXII, pt. 3, Pl 11, (1905).

Laterite beds, Betwa River. 1965

Penchgani Laterite Tableland, close view of Top. 1966

Great Himalayan Ranges in Lahul. 2020

Section from the Himalayas to the Naga Hills. 2021
(*Quart. Journ. Geol. Soc. Lond.*, Vol. CVIII, p. 34, Pl. IV. fig. 2.)

CHAPTER XI

PAGE

PURANA.—Northern part of the Peninsula . . . 379

CHAPTER XII.

PURANA.—Possible representatives in the Himalaya and in Burma 432

CHAPTER XIII.

PURANA.—Dykes and possible equivalent 469

VOLUME II.

CHAPTER XIV.

PURANA or EARLY PALAEOZOIC.—The Vindhyan system—the Kurnool series and other supposed equivalents 485

CHAPTER XV.

CAMBRIAN, and possible equivalents 562

CHAPTER XVI.

ORDOVICIAN 598

CHAPTER XVII.

SILURIAN 635

CHAPTER XVIII.

DEVONIAN, and possibile equivalents, of Northern India 661

CHAPTER XIX.

DEVONIAN-CARBONIFEROUS-PERMIAN Sequence, and doubtful equivalents, in Burma 679

CHAPTER XX.

Marine Facies of the CARBONIFEROUS and PERMIAN and the Extra-Peninsular GONDWANA deposits of India proper 732

CHAPTER XXI.

Extra-Peninsular TRIAS 851

CHAPTER XXII.

GONDWANA SYSTEM of the Peninsular Region . 909

CHAPTER XXIII.

PAGE

Individual GONDWANA EXPOSURES 1017

CHAPTER XXIV.

GONDWANA Continent 1074

CHAPTER XXV.

Marine JURASSIC and some equivalents . 1126

CHAPTER XXVI.

Marine CRETACEOUS and some equivalents . . 1219

VOLUME III.

CHAPTER XXVII.

DECCAN Trap and Associated Sedimentaries, and some possible equivalents 1345

CHAPTER XXVIII.

Extra-Peninsular Granitic Intrusions . . . 1417

CHAPTER XXIX.

TERTIARY.—PALAEOCENE and EOCENE . . . 1472

CHAPTER XXX.

TERTIARY.—OLIGOCENE of India 1617

CHAPTER XXXI.

TERTIARY.—LOWER MIOCENE of India 1638

CHAPTER XXXII.

TERTIARY.—OLIGOCENE-MIOCENE Sequence in Burma 1686

CHAPTER XXXIII.

TERTIARY and QUATERNARY.—UPPER MIOCENE, PLIOCENE and PLEISTOCENE (SIWALIK) sequence 1736

PAGE

CHAPTER XXXIV.

Later TERTIARY and POST-TERTIARY Volcanic Activity in Burma and the Bay of Bengal . . 1850

CHAPTER XXXV.

Additional PLEISTOCENE and RECENT deposits, exclusive of the Indo-Gangetic Alluvium . . 1878

CHAPTER XXXVI.

LATERITE 1960

CHAPTER XXXVII.

The INDO-GANGETIC and BRAHMAPUTRA ALLUVIUM 1980

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The HIMALAYA and the Relationship of it and its continuations to the Indo-Gangetic and Brahmaputra Plain 2017

A Geological Map of India 1":96 miles accompanies each of the three volumes. The 1":32 miles map, a Geological Survey of India Publication, often referred to in the text of the Manual, was published separately.

A MANUAL

OF THE

GEOLOGY OF INDIA AND BURMA.

CHAPTER XXVII.

THE DECCAN TRAP AND ASSOCIATED SEDIMENTARIES, AND SOME POSSIBLE EQUIVALENTS.

Extent. Name. Physical features and vegetation. Relationships. **The Lameta series**: Stratigraphical position ; Lithological characters ; The succession at Jubbulpore ; Succession in Nagpur and Bhandara ; Gujarat ; Relations to the beds below ; Relations to the beds above ; Induration caused by the Traps ; Mode of occurrence and extent ; Fossils ; Doubtful Infra-Trappean beds ; Pijdura ; Pachmarhi ; Narayanpur ; Ellichpur ; Cutch ; Dhamni and Dongargaon ; Age of the Lameta formation. **Deccan Lavas**: General character ; Rock structures ; Inclusions ; Fragmentary material ; Green earth ; Red Bole ; Petrological characters ; Secondary minerals ; Chemical composition ; Folding in the Traps ; Faulting in the Traps ; Thickness of the Lava beds ; Distribution of vesicles ; The floor of the Traps ; Crater-like fumaroles ; The Lonar Lake ; Total thickness of the Deccan Trap formation. **Inter-Trappean beds** ; Two principal horizons ; **(a) Lower Inter-Trappeans**: Position ; "Pseudo-Inter-trappeans" ; Lithological character ; Thickness and mode of occurrence ; Organic remains ; Water-bearing proclivities ; Rajahmundry Inter-Trappeans ; **(b) Upper Inter-Trappeans**: Thickness and lithological character ; Organic remains ; Ahmedabad Boring ; Trap Intrusions. Origin and Mode of Formation of the Traps. Unusual Types. **Age of the Deccan Trap suite, and evidence thereupon from outlying occurrences**: General evidence ; Outlying occurrences. Foreign Simulations. **The Serpentine Intrusions of Burma**: The Andaman Islands ; Thaton ; The Arakan Yoma ; The Jade Mines ; Bhamo and Myitkyina ; Kachin ; Kalaw, Southern Shan States ; Malaysia.

Extent.—Occurring stratigraphically above the Cretaceous beds of the Peninsula is a series of volcanic rocks which form one of the most prominent and widely spread of all the rock systems found in this region. In superficial area the Deccan traps are only exceeded within the limits of peninsular India south of the Indo-Gangetic plain, by the metamorphic rocks. Although the traps are far inferior in thickness to the Vindhyan and Gondwana formations, their remarkably close approach to horizontality, throughout a great part of the region covered by them, enables them to conceal all older rocks.

Some idea of the extent of the area occupied by this formation may be gained from the fact that the railway line from Bombay to Nagpur, 519 miles long, never leaves these volcanic rocks until it is close to the Nagpur station, and that the traps stretch without a break from the sea coast at Bombay eastwards to the temples of Amarkantak at the head of the Narbada, and from the vicinity of Belgaum to

north of Guna. Great as it is, this by no means represents the whole area originally occupied by these great lava floods. Outliers are found east of Amarkantak as far as Jamira Pat in Sarguja, to the southeast a small outcrop occurs close to Rajamundry, whilst to the westward and north-westward the suite is well developed in Kathiawar and Cutch, and is believed to be represented in Sind, Jhalawan, Pishin and Quetta, the Sulaiman range, Waziristan, the country south of Kabul and around Kandahar in Afghanistan, and less certainly in the Chagai district of Baluchistan. We have, therefore, proof of the existence of this volcanic formation throughout more than seventeen degrees of latitude and at least nineteen of longitude. It does not of course necessarily follow that the outlying occurrences were in all cases originally parts of one continuous tract, but the total area covered in Peninsular India today can be little less than 200,000 square miles. Recent researches have shown that, contrary to the original conclusion drawn therefrom, certain occurrences of high-level laterite beyond the confines of the main mass of the Deccan Trap, in these particular cases prove that the latter once extended far northwards into Bundelkhand,[1] and eastwards past Lohardaga to the Raniganj coalfield. According to Dr. C. S. Fox, by far the greater part of the laterite in India is a direct or indirect result of the laterstisation of the basaltic lavas; that this is so is shown by the frequent occurrence in the laterite, especially in Bundelkhand and the Rewa plateau around Panna, of remnants of the geodes which are so characteristic of the Deccan lavas. In the hills west of Lohardaga relics of the trap are seen in kaolinised fragments of basalt, geodes and a bed of lithomarge at the base of the laterite, the whole resting on a granitic gneiss.[2] Still farther east, geodic material which may have been derived from the Trap is found as debris in the laterite of the eastern parts of the Raniganj coalfield.[3] Westwards there is reason to suppose that the Trap stretched over part at least of what is now the Arabian Sea. Basaltic and serpentinous rocks, probably belonging to the Deccan suite, have been recognised in the Quetta-Bolan region of Baluchistan, in the Miram Shah area of Waziristhan,[4] and in central Kashmir, while the extensive outbursts of basalt in the neighbourhood of Melkarez, Kandahar and the Shah Makhsud in Afghanistan are probably to be grouped in the same category. A dense, nearly black, basaltic rock, approaching some of the Deccan Traps in composition, occurs on the eastern edge of the Barmer desert in western Rajputana; it has unknown relationships to a tinguaite found in the same locality intrusive into the Barmer Sandstone (?Lower Cretaceous).[5] The original extent of these enormous spreads of lava in the Indian region of the Gondwana continent can scarcely have been less than a million

[1] E. Vredenburg, Rec. 33, 272 (1906).
[2] Mem. 49, 7, 8 (923).
[3] Mem. 56, 22 (1930).
[4] The age of the serpentine shown on the 32-inch map to the east of Kabul is doubtful.
[5] T. H. D. La Touche, Mem. 35, 93 (1902).

square miles. Even in Burma there are widespread intrusions of peridotite and other serpentine-producing rocks which, though it might be rash to connect them with the same magma reservoir as that of the Deccan Trap, are of the same age as the latter.

In the Deccan Trap were excavated so many of the temples and caves of Buddhistic, Brahmin or Jain origin, for which India has become archaeologically famous. The well-known caves of Elephanta, an island between the city of Bombay and the mainland, date from the tenth century, if not earlier. Many of the caves on Salsette, a much larger island to the north of Bombay, date from the end of the second to the ninth century. The Nasik caves on the neighbouring mainland have been assigned to periods varying from the first century B. C. to the second century A. D. Between Bombay and Poona are the caves of Karli, Bhaja and Bedsa, constructed about 200 B. C.; the first is considered to be the finest *chaitya* cave in India and its dimensions have been compared with those of Norwich cathedral. In the Aurangabad district of Hyderabad State are the rock temples or caves of Ellora, even more famous than the slightly younger ones of Elephanta, and hewn out of the sloping sides of a hill of Deccan Trap ; the most important of this group is Kailas, a perfect example of Dravidian temple, dating from the eighth century. Nearly fifty miles to the northeast are the celebrated Ajanta caves, some thirty in number, the whole having formed a kind of Buddhist college or monastery, excavated in the trap in the precipitous bank of a ravine ; some of these excavations are as old as 200 B. C. The caves near Aurangabad city are of the seventh century. Among the oldest of such religious remains, and dating from about the time of Asoka (263-225 B. C.) are the Junagarh caves, just west of the Girnar peak in Kathiawar.

Name.—The word Deccan, applied to this volcanic suite, mainly of plateau basalts, is derived from the vernacular *dakhan*, meaning "south", and is the name under which that part of the Indian peninsula situated south of the Vindhyan range is known. The old word, "trap" (Swedish, *trapp, trappa,* a stair), now more or less obsolete in geological terminology, has been retained, partly in conformity with a very old custom, and partly because it is peculiarly suitable for a rock responsible for the step or terrace-like profile which is such a feature of the Deccan. The term, Deccan Trap, was first used by W. H. Sykes in 1833.[6]

Physical features and vegetation.—The geological structure of the volcanic region of central and western India is responsible for marked peculiarities of scenery, surface characters being widely different from those prevailing in other parts of the Indian Peninsula. Extensive undulating plains, divided from each other by flat-topped ranges of hills, locally known as *pats* and capped by sheets of basalt with a covering of laterite, occupy the greater portion of the country, the hillsides being marked by conspicuous terraces, often traceable for great distances and due to the greater hardness of the basaltic

[6] Trans. Geol. Soc. Lond., Ser. 2, 4, 409-432.

outcrops. Some parts of the area are characterised by great scarps, some of those in the Western Ghats being 4,000 feet in height, all conspicuously banded with horizontal terraces.

The vegetation of the trap area differs no less conspicuously from that which is found on other formations, the distinction in the dry season being so marked that especially when considered in connection with the form of the surface, it enables hills and ranges of trap to be distinguished at a distance from those composed of other rocks. The peculiar features are the prevalence of long grass, the paucity of large trees, and the deciduous nature of almost all bushes and trees except in the damp districts near the sea. At the same time, the want of large trees is partly due to the reckless cutting to which the forests of India have been exposed for ages, to equally reckless clearing for temporary cultivation of a rude kind and, perhaps more than all, to the practice of burning annually the grass at the commencement of the hot season. The result is that the whole country presents, except where it is cultivated, a uniform straw-coloured surface, with but few spots of green to break the monotony during the cold season, from November till March, whilst from March, when the grass is burnt, until the commencement of the rains in June, the black soil, black rocks and blackened tree stems present a remarkable aspect of desolation. During the rainy season, however, the country is covered with verdure, and in many parts has distinct beauty, the contrast afforded by the black rocks serving rather to bring into relief the bright green tints of the foliage.

Relationships.—Intercalated between the extensive flows of the Deccan Trap lavas are occasional, thin sedimentary deposits, spoken of as Inter-Trappean beds, and in nearly all cases of fresh-water origin. They occur only among the lower and upper traps and are absent from the middle portion of the formation. From this it is deduced that the volcanic energy was less and more partial, with longer periods of intermission, at the commencement and towards the close of the Trap period than during the middle thereof.[7] At the base of the traps in many places, between them and the older rocks of the peninsula, similar sedimentary silts are found. These Infra-Trappean deposits are likewise in nearly all cases of lacustrine or fluviatile type, and are then known as Lameta beds. What may be the marine equivalents of the Lametas, *i.e.*, the Bagh beds of the Narbada valley and, more doubtfully, the Dudkhur beds of the Godavari district, have been described in the preceding chapter (p. 1261). It is proposed to describe first the Infra-Trappean sediments, next the volcanic rocks, and finally the interbedded Inter-Trappean silts.

THE LAMETA SERIES.

Stratigraphical position.—At one time the Lameta was supposed to be a representative of the Mahadeva group of the Gondwana

[7] W. T. Blanford, Mem. 6, pt. 2, 155-6 (1867).

system. Although further examination has led to the conclusion that the Mahadevas are more ancient, it is probable that the Lametas bridge most of the interval between the top of the Upper Gondwanas and the traps which overlie the former. The Lameta beds are so closely associated with what appears to be the lowest trap, that they are best considered as part of that series. The name is derived from Lameta (Lamethi) Ghat on the Narbada river, a few miles south-west of Jubbulpore, and the section here must be regarded as the type section although the beds are somewhat more completely developed elsewhere.

Lithological characters.—Excluding simulations of secondary origin, the Lameta beds of central and western India consist of limestones, sandstones, and clays or shales of fresh-water origin, and usually of a pale colour. The most typical and persistent bed is a limestone which is frequently the only member of the formation present. Occasionally it is pure but in the majority of cases it is characteristically full of sand and small pebbles, the result being a calcareous grit rather than a limestone. In numerous instances, some of the small pebbles are composed of red jasper, the occurrence of which is very typical; the rest consist mostly of quartz and quartzite. Another usual feature of the limestone is an abundance of segregated chert in irregular or lenticular masses. This silicification is a secondary phenomenon caused by percolating siliceous water from the overlying trap.[8] It has affected not only the limestones but also the sandstones of the stage and in the Chhindwara district has penetrated into the underlying crystallines; in some cases the limestone is largely replaced by the chert.[9] This gritty Lameta limestone, with its included chert nodules, is found over a very extensive tract of country in the Central Provinces, and appears to be rarely absent throughout any large area in which the base of the traps is exposed.

One of the Lameta limestones in the Wardha valley exhibits cone-in-cone structure, another a honeycomb arrangement; other limestones of this area have a reticulate structure affecting stringers of different colour.[10]

In the Linga area of the Chhindwara district, and in parts of Hyderabad, it is not easy to draw a line between a true sedimentary Lameta limestone and what appears to be a mere calcification of the upper surface of the subjacent gneiss. In the Linga area the gritty impure Lameta limestone in some sections has every appearance of passing gradually down into the underlying gneiss and granite;[11] in parts of Hyderabad the Lameta limestone is simulated by a matrix of calcite containing small patches of gneiss and remnants of strained quartz.[12] In fact, some of the thinner bands to which the term Lameta has been applied appear to be no more than soil caps on the gneiss

[8] Gen. Rep. Rec, 43, 33 (1913).
[9] L. L. Fermor, Rec., 33, 173 (1906).
[10] T. W. H. Hughes. Mem. 13, 88 (1877).
[11] L. L. Fermor & C. S. Fox. Rec., 47, 86 (1916).
[12] Hallowes. Rec. 49, 220 (1918).

impregnated with lime and silica derived from the overlying basalt and lime derived either from the basalt or, as Blanford thought more probable, from the underlying gneiss. Even in some of the more extensive occurrences, it is doubtful whether the limestone is of primary origin and not merely a secondary deposition of external origin.

After the limestone the most commonly found bed is a rather fine, porous, earthy sandstone, usually of a greenish colour. Coarser varieties and conglomerates also occur and, when porous, are often impregnated with oxides of manganese. In the Panna State of Bundelkhand the Lameta stage consists usually of a rather loose sandstone, indurated only in its uppermost layers as a contact effect of the overlying trap.[13] The clays in the Lametas are red or green, very frequently sandy or marly, and sometimes contain nodular carbonate of lime; they are more local in occurrence and appear to be more limited in their extension. These beds are described as passing from one into the other; the limestone is infrequently merely the sandstone cemented by carbonate of lime, while the marls may be an argillaceous form of the limestone. In the Jubbulpore, Nagpur and Bhandara districts, a definite sequence can be made out which, in the first named area, is persistent over a tract of considerable size though obscured here and there by numerous post-Trap faults. In many cases, however, no persistent sequence is observable. Where the group is reduced to 20 feet or less in thickness, it is usually found to consist solely of either the gritty limestone or the earthy greenish sandstone.

The succession at Jubbulpore.—The Lameta beds of Jubbulpore have been the subject of special study by Dr. C. A. Matley who has established there the following succession:[14]

	Thickness
Deccan Trap	
Lameta beds	
(e) Upper sands	up to 15 or 20 ft.
(d) Upper limestone (an inconstant local zone)	up to 10 ft.
(c) Mottled Nodular beds	40-50 ft.
(b) Main or Lower Limestone . . .	3-12 ft. and more.
(a) Green sand	7-50 ft.

JABALPUR STAGE OF THE GONDAWANAS.

The total thickness in this typical area varies from 70 to 160 feet, and the formation is described as essentially a sandy one, grains of sand occurring abundantly throughout. The lowest zone is a soft,

[13] E. Vredenburg, Rec. 33, 272 (1906).
[14] Rec. 53, 143-144 (1921); this differs somewhat from Blanford's record of the same section [Mem. 6, pt. 3, 216 (1869)].

current-bedded, friable sandstone usually of a green colour but occasionally variegated in a wide range of colours. A few tiny pebbles, mostly of quartz, are found in it. At times it becomes a hard rock with a ferruginous cement. The Lower Limestone is of the type already described, and is sometimes so sandy as to become a calcareous sandstone. Ordinarily the limestone is concretionary; at times it has at the top a conglomeratic layer of large pebbles which include some of the limestone evidently derived from the underlying material by contemporaneous denudation. This zone, owing to its resistance to erosion, forms conspicuous escarpments and wide shelves of bare or nearly bare rock. The next zone consists of from 40 to 50 feet of red, green and mottled sandy and clayey beds, characterised by many sandy and calcareous concretions and weathering in consequence to a coarse rubble. Some of the bands approximate to very impure nodular and sandy limestones; others contain few or no concretions. Small pebbles occur sparingly throughout this zone, and the beds are rarely laminated. The Upper Limestone is an inconstant zone and appears to be merely a local variation of the top of the Mottled Nodular Beds, down into which the passage is at times very gradual. It is much less pure than the Lower Limestone; in fact it is generally so sandy as to be more often a calcareous sandstone rather than a limestone. The Upper Limestone is usually covered by buff and brown sands. Ten or eleven miles east of Jubbulpore the Lameta beds show the same succession except that the Upper Limestone is not present.

In the type area of Lameta Ghat, 9 miles southwest of Jubbulpore, the Lameta beds occupy a faulted strip between Jabalpur beds to the north and Deccan Trap to the south;[15] here the sequence found at Jubbulpore can be recognised except that the Upper Sands are represented by a fine-grained quartzite, and the lowest Greensand has lost its green colour.

Succession in Nagpur and Bhandara.—In Nagpur and Bhandara the following sequence is recorded by Bhattacharji,[16] though all zones are not present in every Lameta section:

4. Calcareous grit,
3. Red and green clay,
2. Patchy limestone with chert,
1. Chert.

The chert is probably a secondary product. The red and green clays near Pahmi have yielded a number of fossils including remains of a dinosaur, chelonian plates and some lamellibranchs probably belonging to the Unionidae.

Gujarat.—In Gujarat a conglomeratic bed with a siliceous or calcareous matrix forms the base of the formation.[17] This is described as grading progressively up into gritty, siliceous or calcareous types, with the result that the bulk of the upper oortion of the succession is either a massive, earthy limestone or a gritty calcareous

[15] C. A. Matley, Rec. 53, 166 (1921).
[16] Gen. Rep. Rec. 65, 104 (1931).
[17] R. C. Gupta and P. N. Mukherjee, Rec. 73, 192 (1938).

sandstones, varying in colour between gray and brown. The component bands are often characterised by irregular concretions of secondary silica and by both rounded and angular quartz pebbles. In the upper layers cherty and chalcedonic stringers and veinlets occur in considerable force. The limestone is frequently mottled with limonitic spots and blotches. Numerous lenticular outcrops of the beds are recorded by Gupta and Mukherjee, one of them with indistinct fragments of lamellibranch shells in the siliceous limestone; the latter under the microscope shows rounded or sub-angular grains of quartz in a ramifying calcareous groundmass often tinged with limonite. Another outcrop includes masses or pebbles of quartz and red jasper. The lithology and mode of occurrence of these sediments suggest deposition in shallow inland basins.

Relations to the beds below.—In the Jubbulpore area Matley is of opinion that the sequence from the top of the Jabalpur stage to the base of the Lameta[18] is a conformable one. In two places the Lameta greensand is seen to lie on an eroded channel in the Jabalpur clays, the channel being a few inches deep in one case and as much as four feet in the other, but the erosion has the appearance of being contemporaneous or nearly so and the result of the currents which deposited the current-bedded greensand. All zones, from those forming the top of the Jabalpur stage to the Deccan Trap are present in their recognised order throughout the area surveyed by Matley who found also that the Jabalpur-Lameta junction in the majority of cases, runs evenly along an uneroded surface of the white Jabalpur clay beds, that the base of the Lameta greensand is characterised by no conglomerates of white clay fragments, and that undulations in the clays below the junction are continued into the overlying greensand, showing that the flexuring was of post-Lameta date. A few miles E.N.E. of Jabbulpore the white clays of the Jabalpur stage are described as passing up with apparent conformity into the thick, current-bedded greensand of the Lametas, in the top layers of which some dinosaurian bones have been found. The field evidence, therefore, is in favour of the view that the Lameta sedimentation succeeded the Jabalpur clays after only a short interval, since it is thought impossible that these soft clays could have resisted complete denudation for any appreciable length of time.[19] Such a conclusion, however, is difficult to accept unless the Jabalpur series be assigned to some middle part of the Cretaceous instead of to the top of the Jurassic.

Where the floor of the Infra-Trappean sediments is composed of the old crystalline and metamorphic rocks, it is upon the denuded upturned edges of the latter that the Lametas have been laid down. Near Kara hill in the Chhindwara district, for example, there is evidence of a pre-Lameta difference in floor level amounting to 300 feet within ¾ mile.[20]

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[18] Rec. 53, 143 (1921).

[19] Rec. 53, 148 (1921).

[20] L. L. Fermor, Rec. 33, 165 (1906).

Along the southern and part of the eastern margin of the Aravalli tract in Jhabua State, platforms of Lameta beds can be seen lying horizontally and unconformably on the schists and granites.[21] In the area of the Dhar Forest, Indore and the Nimar district, where the sandstones and conglomerates of the Lametas rest on a peneplain of Bijawar rocks, the latter appear to have undergone brecciation followed by a re-arrangement of the breccia by water of the Lameta epoch and accompanied by a sort of lateritisation; the result is a soft, porous, loamy matrix, often replaced by manganese oxides, containing angular fragments of quartz, hornstone, quartzite and other rocks.[22] Blanford and Vredenburg describe the Lametas as passing into the marine Bagh beds of Cretaceous age, but Bose, who mapped the area in more detail, concludes that the Lametas, wherever they are in contact with the Bagh beds, overlie them unconformably.

Relations to the beds above.—A conformable junction of the Lametas with the overlying Deccan Trap is claimed to occur in the Jubbulpore area[23] and in the Narsinghpur district.[24] In the Kanhan valley of Nagpur and Chhindwara, however, previous to the outflow of the trap, the Lametas appear to have suffered a limited amount of sub-aerial erosion which, besides excavating valleys in the Lameta beds themselves—sometimes even cutting down to the underlying gneiss—also removed any of those sediments that may have been deposited on the higher gneissic hill-tops.[25] In some sections of the Kanhan valley the absence of the Lameta limestone or its equivalent grit may be due to non-deposition rather than to pre-Trap denudation. At Deni and other places in the Nagpur district, the Lametas were found by Bhattacharji to be folded, but whether such local folding could not have been caused by the very advance of the lava flood is a question worth consideration; the floor over which the lowest flow was poured out in this area is described as uneven.[26] On the whole it is safe to conclude that, though widespread and extensive there was no denudation of the Lametas before the advent of the trap, there was local erosion, as might be expected, here and there; in this manner we may explain the fact that, between the outcropping patches of Lameta beds, where the trap rests upon a formation older than Lameta, it sometimes does so at an elevation sufficiently low to show that the absence of the Infra-Trappean bed is not due to this part of the ground having been above the water in which the Lametas were deposited. Nevertheless, the Lametas can never have been co-extensive with the base of the Trap, because the surface on which the latter rests is extremely uneven, and many portions of it must have been above the level at which the Infra-Trappean beds were deposited.

[21] Gen. Rep. Rec., 37. 44 (1908).
[22] L. L. Fermor. Mem. 37. 368 (1909).
[23] C. A. Matley, Rec. 53. 146 (1921).
[24] Gen. Rep. Rec. 35. 55 (1907).
[25] L. L. Fermor, Rec. 33, 165 (1906).
[26] Gen. Rep. Rec. 65, 104 (1931).

Induration caused by the traps.—In Jhabua State a bed of coarse grit belonging to the Lameta is said to show signs of having been burnt by the basalt now capping it.[27] In the great majority of cases, however, the Lametas do not seem to have been altered by the trap flows.

Mode of occurrence and extent.—Typically the Lameta beds are seen projecting in the form of an irregular, horizontal shelf or platform from beneath the edge either of the main mass of the Deccan Trap or of outliers of the same rock. Occasionally this platform is of appreciable width, as in Nagpur, Jubbulpore, Jhabua State and Rewa Kantha, but as a rule the outcrop forms but a very narrow fringe to the lowest volcanic flow. The group is well developed in the Central Provinces, in the Chanda, Nagpur, Chhindwara, Seoni, Mandla, Jubbulpore, Narsinghpur and Saugor districts, and is rarely absent for any considerable distance along the boundary of the volcanic area from the Godavari to Bundelkhand. West of the latter locality it occurs in north Gwalior and Jhalawar, Jhabua, the Panch Mahals and Rewa Kantha, south Gwalior and Ali-Rajpur ; south of the Godavari it has been recognised in the centre of Hyderabad State, and is probably present further south in the southern parts of the Bombay Presidency.

Fossils.—The Lameta group, as a rule, is unfossiliferous. The plant remains known to occur include some angiospermous varieties which have not been further identified, mollusca are very rare, and the few fish remains come from a horizon which may be somewhat younger than that of the true Lameta. The most important organic relics are those of dinosaurs found in the Jubbulpore area just above and below the Main Limestone, the bones showing evidence of having been washed about and damaged before petrifaction. From the "Sauropod bed", just below the limestone, Baron Von Huene has identified species of the sauropods, *Titanosaurus*, including *T. indicus*, a form not less than 60 feet long, and *Antarctosaurus septentrionalis* v. Huene; *Titanosaurus* is a large genus found also in Madagascar, Patagonia and Europe in horizons varying from Wealden to Danian.[28] The "Carnosaur bed", immediately above the Main Limestone, includes remains of *Titanosaurus* and indeterminate sauropods, and parts of several carnosaurs; among the latter Huene identifies, *Indosuchus raptorius* v. Huene, *I. matleyi* v. Huene, some Coelusaunians—mostly vertebrae and teeth—including *Compsosuchus solus* v. Huene, *Laevisuchus indicus* v. Huene, *Jubbulpuria tenuis* v. Huene, *Cœluroides largus* v. Huene, *Dryptosauroides grandis* v. Huene, *Cœluroides largus* v. Huene, *Dryptosauroides grandis* v. Huene, other indeterminate fragments, some stegosaurian remains including *Lametasaurus indicus* Mat. which was protected by dermal scutes and probably carried, like the Canadian *Ankylosaurus*, a club at the end of its tail, and several remains of Testudinata. Lying on the

[27] Gen. Rep. Rec. 37. 44 (1908).

[28] Baron Von Huene & C. A. Matley, Pal. Ind., New Ser.. Vol. 21, Mem. 1, 7 (1933).

surface with the bones a fossil tree is recorded by a very early observer in this district, General (then Captain) Sleeman. Between Tamia and Gof Terai, in the Chhindwara district, separating the Gondwanas from the Trap is a thin band of calcareous conglomerate on the surface of which is some fossil wood, some of it palmaceous; this is perhaps a local variation of the usual Lameta.[29]

The Lametas have been recognised at several localities to the northeast of Jubbulpore, and also at Kareia, 40 miles W. S. W. of the same town; from the latter have been obtained large vertebrate remains.

At Takli, near Nagpur, beds beneath the trap have yielded the carnosaurian tooth, *Massospondylus rawesi* Lyd. and a *Paludina* apparently identical with the inter-Trappean *P. deccanensis*.

At Nawapet in central Hyderabad, Hallowes found resting on calcified gneiss and covered by the Deccan basalt, thin lenticular beds of pale, calcareous shale containing large numbers of a fresh-water Unionid determined by Baini Prashad as *Indonaia pascoei* Prash. Near Anantawaram also, between the gneiss and the lowest basalt flow occurs a brown chert with indeterminable fossil fragments, probably of Unionidae.[30]

From the Lametas of the Chhindwara district, Sir Lewis Fermor obtained one specimen having some resemblance to the genus *Turritella*, and numerous specimens of *Paludina*.[31]

Doubtful Infra-Trappean beds.—Before considering the Lameta fauna further, it is necessary to remind oneself that what appears to be the lowest-lying trap in one locality is by no means necessarily of the same age as the lowest trap in another, and consequently, any such sedimentary deposits as have just been considered, although subjacent to what is locally the basal trap in each case, are not necessarily contemporaneous. In a lava suite covering such an immense area as does the Deccan Trap, it is in fact highly unlikely that the basal lava everywhere belongs to the same flow or even to flows which are inappreciably different in age. Furthermore an Inter-Trappean bed might overlap the edge of an underlying flow, so as to rest upon an older rock, and thus simulate in its stratigraphical position the true Infra-Trappean or Lameta rocks; such an Inter-Trappean bed might even rest upon a true Lameta bed instead of upon the more ancient floor-rocks of the Deccan Trap series. Yet again, what appears to be the lowest trap, overlying apparent Infra-Trappean sediments, might be the emergence of a sill from underneath basalts of older age.

Pijdura.—It is just possible that such an example of a deposit, Infra-Trappean in appearance but perhaps of Inter-Trappean age, is seen at Pijdura (Pisdura), about eight miles north of Warora in the Chanda district, and some 200 miles distant from Jubbulpore. Hislop's collections from this locality have unfortunately been lost

[29] Gen. Rep. Rec. 63. 113 (1930).
[30] Rec. 60. 311 (1927).
[31] Gen. Rep. Rec. 43, 33 (1913).

but they are said to have included coprolites, some of very large size, an abundance of the large *Bullinus* (*Physa*) *prinsepii, Paludina deccanensis* and other shells of the Inter-Trappean, a chalonian named by Lydekker *Hydrospis leithi* and some *Titanosaurus* bones; Matley's collections include *Titanosaurus blanfordi* Lyd., ? *Antarctosaurus* sp., and forms comparable to *Titanosaurus indicus* Lyd. and *Laplatasaurus madagascariensis* (Dep.). From the presence of the last mentioned genus and species, the fauna of Pijdura is inferred to be contemporaneous with a fauna described by Deperet from Madagascar and assigned by Lemoine to the Turonian-Emscherian.[32] Baron von Huene's conclusions were that the Pijdura beds might be assigned to the lowest Senonian (*i.e.*, the lower Emscherian), and the Lametas of Jubbulpore to the Turonian; the examination of additional bones from Jubbulpore, however, may lead to the acceptance of a younger age for the beds containing them, in which case the Pijdura fauna is just as likely to be Infra-Trappean as the Jubbulpore assemblage.[33]

Pachmarhi.—Among the occurrences of what have been called Lametas, the beds south of Pachmarhi may be looked upon as suspect. A fossil palm tree has been obtained from these sediments, which vary from a few feet of calcareous conglomerate to a red boulder clay or a limestone. In the Betul district (Morand river area) this red clay in places contains irregular glassy fragments in addition to the angular grains of quartz, and thus exhibits an agglomeratic character which presupposes the presence of volcanic materials before the deposition of the sediments;[34] the latter would thus appear to be Inter-Trappean rather than Infra-Trappean.

Narayanpur.—Large fossil bones, almost certainly of dinosaurs, associated with fossil wood and tufaceous limestone, are recorded from Narayanpur, near Saugor, but appear to have been lost; the bones were silicified like the Inter-Trappean fresh-water mollusca found in the district.[35]

Ellichpur.—In this somewhat doubtful category we may include some Infra-Trappean beds near Ellichpur in Berar, which have yielded *Melania* and *Corbicula*.[36] Beds in a similar position at Todihal, 15 miles N.N.E. of Kaladgi in the southern Maratha country, are characterised by *Physa prinsepii*.[37]

Cutch.—With the beds now being considered may be classed some grits found in the Cutch peninsula. In some localities these beds fill up hollows in the Jurassic rocks; not only are they unconformable to the latter but their successive members overlap each other on to the eroded hollow surface of the Mesozoics. In places these beds are clearly seen lying beneath the base of the Trap; elsewhere they occur in isolated patches, sometimes at a considerable distance from the trap. That they are Infra-Trappean in age, in spite of their

[32] *Handb der regionalen Geol.* Madagascar, 6, 4, pp. 11-13 (1911).
[33] H. Crookshank, Proc. 24th Ind. Sci. Congr. 461 (1937).
[34] H. Crookshank, Mem. 66, 274-5 (1936).
[35] Journ. Bomb. As. Soc., Vol. 5, 179-335 (1854).
[36] W. T. Blanford, Mem. 6, pt. 3, 283 (1869).
[37] R. B. Foote, Mem. 12, 193 (1876).

apparent position is indicated by their agglomeratic nature. They form a peculiar, soft, loosely granular, obscurely stratified group of earthy and sandy rocks largely composed of trappean materials which, by weathering out, give rise to a spongy aspect and easy disintegration. The intimate association of trappean blotches and lumbs with sub-angular quartz grains in a rubbly calcareous matrix suggests a close connection with the earlier volcanic flows. The only fossils are a few woody fragments. The rocks often weather to a greenish orange though the colour becomes darker with an increase in the proportion of igneous material. The thickness of the group is anything up to 200 feet, but is generally less than the latter figure.[38]

A horizontal band of grit and conglomerate from 10 to 80 feet thick, lying beneath the Trap in the Betul district, is thought by H. Walker to belong to the Mahadeva stage of the Gondwana rather than to the Lameta; the beds resemble neither the latter nor the Inter-Trappean.[39]

Dhamni and Dongargaon.—East of Warora, and only a few miles distant from Pijdura, fish remains were collected by Hislop in supposed Lameta beds at Dhamni and Dongargaon, and have been described by Dr. A. Smith Woodward.[40] One of these is a Teleostean, *Eoserranus hislopi,* in addition to which there are two species of ganoids, *Lepidosteus indicus* and *Pycnodus lametae.* In the opinion of Dr. Woodward the age of this fish fauna lies between the Danian and the Upper Eocene, and indicates an Inter-Trappean rather than a Lameta horizon. The beds are covered by the trap but their base is not exposed and it is not known whether they rest on trap or on older rocks. Matley speaks of them as quite different in character not only from the type Lameta beds but also from the beds at Pijdura. Close to Dongargaon are greenish and brownish clays with bands of white and cream-coloured limestone dipping in places at 20° or 30°. Besides the fish, the beds have yielded casts of the stems or roots of trees, and a *Melania*-like gastropod. Between Dongargaon and Pauna is exposed an Inter-Trappean bed undoubtedly intercalated in the trap. Between Pauna and Dhamni, laminated limestone and sandstone are seen. Near Dhamni abundant calcareous septarian nodules in the form of flattened spheroids 1½ to 3 feet in diameter, are conspicuous on the surface of the jungle. In Batara is exposed a cream-coloured or yellow, compact, thinly laminated limestone, which is used on a small scale for building purposes. It is quite unlike the Lameta limestone, and is seen strewn over the surface of the fields and along the cart track.[41] The position of all these beds may be Inter-Trappean; they are considered here because of their apparently Intra-Trappean position.

Age of the Lameta formation.—Assuming the age of the Pijdura fauna to be Santonian, that of the Jubbulpore Lameta, which, unless corrected by further evidence, is somewhat earlier, should be approximately Turonian, a conclusion supported by the plentiful presence of allosaurids in the Carnosaur beds. These determinations would

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[38] A. B. Wynne. Mem. 9, 56-57 (1872).
[39] Gen. Rept. Rec. 55, 35 (1923).
[40] Pal. Ind. New Ser., Vol. 3, Mem. 3 (1908).
[41] C. A. Matley, Rec. 53, 159-60 (1921).

bring the age of the Jubbulpore Lametas surprisingly close to that assigned on entirely independent evidence to the Lametas of the western Narbada valley. The latter are comparatively constant in character and have been divided into an upper division in which prevailing sandstones are associated with shales and calcareous beds, and a lower composed of conglomerate with well rounded pebbles embedded in clay or loose sand or cemented by calcite and oxides of iron and manganese.[42] The only fossils recorded are abundant specimens of *Bullinus prinsepii*[43] but the beds are believed to pass laterally into the Bagh Beds, to which a Turonian age has recently been assigned on the evidence of their ammonites. The passage from the marine Bagh to the fresh-water Lameta is not definitely substantiated, but was thought to take place close to Barwari, which would thus be the esternmost limit of trespass of the Cenomanian sea.[44] A similar lateral passage has been traced by H. Walker and A. M. Heron in Jhabua State. Here the northern exposures are of Lameta type—calcareous, pale in colour, highly sandy, occasionally cherty, their uppermost layers characterised by well rounded pebbles of quartz, quartzite and bright red jasper.[45] Southwards there is a great increase in conglomeratic beds, grits become frequent, and locally the rocks are entirely silicified. Fossiliferous limestones are not uncommon, most of them being affected by silicification; the fossils include forms of *Rhynchonella*. *Terebratula* and *Ostraea*, several lamellibranchs, gastropods and bryozoa. Before leaving this subject, it must be frankly admitted that the distinction between true Infra-Trappean beds, *i.e.*, deposits laid down before the commencement of the Deccan Trap disturbances, and Inter-Trappean sediments, rests upon unsatisfactory grounds. The fossil evidence is as inconclusive as the stratigraphical, and the state of our knowledge may be summarised as follows. The first outpouring of trap and ash would certainly have spread over and preserved some of the fluviatile and lacustrine sediments which covered the surface of the pre-Trap land. Similar fluviatile and lacustrine deposition took place between the outbursts of lava and ash, and were but a continuation of those which preceded the volcanic disturbance. The distinction between Infra- and Inter-Trappean, therefore, is somewhat arbitrary and in any case is often difficult to make out in the field. If the sediment lies upon a Trap flow, or if it contains volcanic debris which could not have been derived from volcanic rocks other than those of the Deccan Trap, it is obviously Inter-Trappean. In other cases an element of doubt must frequently exist. Both Infra-Trappean and Inter-Trappean deposits are but the restricted continuation of the Gondwana sedimentation.

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[42] Gen. Rep., 20 (1902-3).
[43] P. N. Bose, Mem. 21, 45 (1884).
[44] Gen. Rep. 20-21 (1902-3).
[45] Gen. Rep., Rec., 37, 45 (1908).

DECCAN LAVAS.

General Character.—Throughout the Trap area the usual rock is some form of basalt or dolerite, the prevailing type being a dark green or nearly black basalt without olivine and often with much basic glass.[46] There is a wide degree of variety in the textural characters presented by the beds. Some are excessively compact, hard and homogeneous, the crystalline structure being minute (amamesite), others are coarsely crystalline, and these frequently contain olivine in appreciable quantity; one variety is porphyritic, with large tabular phenocrysts of glassy felspar, white or green in colour. Like the plateau basalts of other parts of the world, the Deccan flows all show a high percentage of ferrous oxide, a feature thought to be responsible for the high degree of fluidity when molten. From partial decomposition, many of the basalts are soft and earthy. Perhaps the most striking peculiarity is the prevalent vesicular character, the amygdales, chiefly of zeolite or agate, sometimes constituting the principal part of the rock; these amygdales are very often coated with a layer composed of one or more of the minerals, palagonite, chlorophaeite, delessite, diabantite, celadonite or glauconite; the prevalence of these green mineral substances is highly characteristic. Almost throughout their range the Deccan Traps may be recognised by the occurrence of the amygdaloidal basalts with green earth, or of the porphyritic rock with crystals of glassy felspar. In addition to simple surface flows, intrusions in the form of dykes and sills are plentiful.

In contrast to the predominant basic types, local differentiation in the Panch Mahals, Kathiawar and a few other localities has given rise to rhyolitic lavas, sometimes pumiceous, and lacolithic intrusions of acid or intermediate composition. Trachytic rocks are rarely found. Ash beds and calcareous lacustrine deposits vary the monotony of the flows.

Rock Structures.—Exfoliating concretionary structure is common in the softer forms of basalt which have undergone some amount of decomposition, but is never seen in the hard, compact beds; frequently the hard, unaltered, spheroidal cores, which may easily be mistaken for rolled fragments, are to be found scattered over the surface of the bed from which they have weathered out. Columnar structure is less common; although more frequent in intrusive dykes, it has been observed in some of the compact, basaltic flows. It is often seen in the lowest flow—a very thick one—west of Hoshangabad, in the Narbada valley, and in one of the lower flows in Malwa. Another good example is recorded in the lowest flow of the Jubbulpore area[47] and the third flow in the railway quarries near Linga, in the Chhindwara district, is described as often beautifully columnar. A roughly columnar structure is sometimes discernible radiating from the craterlets which characterise the Linga area and which

[45] C. A. McMahon, Rec. 16, 42-50 (1883), Rec. 20, 107-111 (1887); C. S. Middlemiss, Rec. 22, 226-235 (1889).
[47] C. A. Matley, Rec. 53, 146 (1921).

will be referred to again. Fermor and Fox suggest that the radiating arrangement of the columns, occasionally seen in Deccan Trap dykes, such, for instance, as that near Gujri, to the northwest of Maheswar, in the Narbada valley, may be due to the maintenance of liquid pools in the dyke after the main mass had solidified, the cooling of the pool proceeding inwards from the periphery. Columnar structure is not confined to the basalt but has been observed in the dolerites.[48]

Inclusions.—Inclusions in the Deccan lavas are either extremely rare or have escaped notice. A small mass of coaly shale, of about a cubic foot in dimension, has been recorded as occurring in the trap at Indore, and evidently represents a fragment of sedimentaries torn off and engulfed in the Deccan magma.[49] Inclusions of Inter-Trappean sedimentaries caught up by an intrusive sill in the Bombay area will be noted in the sequel.

Fragmentary Material.—Beds of volcanic ash are common, so common indeed in places as to form a very considerable proportion of the sequence. They appear to be much more prevalent towards the upper part of the formation, a result due possibly to the fact that the upper part of the series is preserved chiefly near old volcanic foci which characterised the more explosive tendency of the later phases of the disturbance. Ashes are found interstratified with what are believed to be the lower beds on the Narbada, in Baroda, but here again remains of ancient volcanic cores are present. The ash beds often differ but little in macroscopic appearance from the basaltic lavas with which they are interbedded but, on closer examination, their clastic structure can always be readily detected; the blocks of scoriae which they contain generally weather out on exposed surfaces and remain in relief, precisely as on old volcanic cones. Magnificent examples are to be seen on most of the higher portions of the Western Ghats and on the high peaks around Poona, formerly used as hill forts. Amongst the best examples are: the rocks in which the Keneri caves of Salsette are cut; some beds on the Kamatgi Ghat between Poona and Mahabaleshwar; and a conspicuous bed at the lower gateway of the fortress of Singarh near Poona. Ash-breccias also occur in Bombay Island at Flagstaff Hill and Rai Hill, Parel, and in the neighbourhood of Sion Fort. It must not be supposed, from these instances, that the rock is rare; it is in fact found almost throughout the Trap country, though much less common towards the base of the formation. Very frequently a thin bed of ash intervenes between two basaltic flows. An occasional constituent of the ash beds is pumice with its interstices all filled up by the same process as that by which vesicular lava has been converted into amygdaloid.

In some interesting borings put down in Kathiawar and the Ahmedabad district, several volcanic agglomerates, one of them 73

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[48] L. L. Fermor & C. S. Fox, Rec. 47, 93, 94, 125 (1916).

[49] A. L. Coulson, Rec. 71, 434 (1936).

feet thick, and two Inter-Trappean beds of grit and sandstone were encountered, interbedded with 48 basalt flows.[50]

Green earth.—A common feature of a Trap flow is the alteration of its basal portion into a green earth made up of a mixture of celadonite and other secondary products[51], a result of underground weathering which may affect ten feet or so of the rock. This decomposition product between some of the flows of Hyderabad was found by Hallowes to contain crystals of heulandite, derived from the amygdales in the originally fresh basalt. This green earth is found not only between flows but as veins in cracks and fissures in the basalt.

Red bole.—Here and there, throughout the traps, occur beds of red bole, usually only a foot or two thick but occasionally more. Sometimes the bole contains scoriae, and in this case it frequently appears to pass down into the basaltic flow whose upper surface it covers. It has been suggested that the red colour of the boles was produced by the heat of the overlying lava flow acting upon the clay formed by the decomposition of the crust of the lower flow[52], but a simpler explanation is that these red beds are old soils formed in a manner precisely similar to that in which the capping of laterite, so universally characteristic of the trap surface today, originated. In the majority of cases, probably, they are the relics of Inter-Trappean lateritisation, and had assumed their red colour long before they were covered by the superjacent lava. In some instances the bole of the Deccan suite is so uniformly stratified that it has the appearance of having been deposited from water ; here the bole may originally have been a volcanic sand showered down from above and distributed over the underlying lava by torrents and floods.

Petrological characters.—The geological age of Plateau Basalts varies from Pre-Cambrian to Recent. The petrology of representatives of these rocks from several parts of the world, including the Deccan, has been described in some detail by Mr. H. S. Washington.[53] The petrology and mineralogy of selected examples of the Deccan lavas have also been dealt with in two important papers, one by Sir Lewis Fermor[54], and the other by the same authority in collaboration with Dr. C. S. Fox.[55]

The bulk of the Deccan Traps shows a remarkable uniformity in both megascopic character and mineral composition. In nearly all cases the rock is of a black or very dark grey colour, often with a brownish tinge. In texture it varies from a very dense, glassy variety with the semi-resinous lustre of tachylitic basalt, through very fine-grained forms which are the commonest, to doleritic types of varying

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[50] Gen. Rep. Rec., 66, 18 (1932).

[51] L. L. Fermor, Rec. 58, 142 (1925).

[52] C. Lyell, Phil. Trans., 711 (1858).

[53] Bull. Geol. Soc. Amer., Vol. 33, 765-803 (1922).

[54] "On the basaltic lavas penetrated by the deep boring for coal at Bhusawal, Bombay Presidency", Rec. 58, 93-238 (1925).

[55] "The Deccan Trap Flows of Linga, Chhindwara Dist. C. P.", *Rec.* 47, 81-136 (1916).

coarseness. None of the normal Deccan Traps, however, can be described as completely holocrystalline, for even the coarest dolerites of both flows and sills contain an abundance of primary glass.[56] Most of the Deccan Traps are non-porphyritic. Many of them are vesicular, and the variety of the zeolites found in these varieties is well known. As already stated there is often a tendency for the middle portion of a flow to exhibit a doleritic texture. Flow structure is seldom seen.

Excluding olivine, vesicular fillings and alteration products, these basalts are variants of the three minerals, labradorite, augite and iron-ore, with interstitial glass. Labradorite and augite make up about 90 per cent. of most of the more holocrystalline types of the trap, the amount of augite being almost as great as that of the felspar. The iron-ore is often obscured in the finer grained varieties, being contained in the glass which is then very dark. Olivine is often present in one of its altered forms but is rarely found in a fresh condition. Magnetic iron sand, derived from the traps, is frequently found in the streams which traverse the rocks.

The felspar is a labradorite of a composition approximating Ab_1An_2, and is abundant in all normal varieties. The fine-grained, chilled forms of the Trap often possess two generations, one of microlites and the other of small laths. In addition some of the rocks show phenocrysts of larger size, some of them ½ or 1 centimetre across, often with stone inclusions. Twinning is mostly on the albite law, and frequently on the carlsbad as well; pericline twinning is not uncommon, and Fermor records cases of cruciform twins. The phenocrysts, which are often altered to delessite, are sometimes present in the form of isolated prisms, but are more often arranged in glomero-porphyritic groups. Sometimes they are slightly zoned, but zoning is not a characteristic feature. In many cases the phenocrysts contain irregular isotropic patches; other inclusions are composed of a colourless mineral having the same birefringence as the labradorite but a lower refractive index. With the tabular felspar crystals small scales of a red mica are sometimes found.

Augite, as usual in basalts, is abundant, but becomes somewhat less as the glass content increases; in the dense, black, tachylitic varieties of rock it is often very difficult to distinguish. Occasionally it is much more abundant than the felspar. The mineral is an enstatite-augite, slightly brownish to colourless; and non-pleochroic; it is decidedly less brown in specimens containing yellow glass than it is in those with black glass. Twinning on the orthopinacoid is not uncommon. In the more glassy basalts the augite is idiomorphic, showing typical octagonal cross-sections; in the more coarsely crystalline varieties it is sub-idiomorphic to granular. The doleritic forms of the Deccan Traps are more or less ophitic, but in the commoner basalts the two periods of crystallisation appear to have overlapped, and cases are even known where labradorite phenocrysts include granules of augite.

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[56] L. L. Fermor, Rec. 68, 348-9 (1934).

In the majority of specimens irregular grains of magnetite are rather common, and the presence of leucoxene shows that this mineral is titaniferous; sometimes thin plates of ilmenite itself are seen. In some of the fine-grained, holocrystalline basalts the magnetite may be more or less idiomorphic with squarish outline. In many cases these iron ore granules are associated with and often partly or entirely enclosed by the augite grains; according to Sir Lewis Fermor, the iron ore granules evidently crystallised after the labradorite, and on the whole commenced to crystallise before the augite, though they encroach to some extent on both minerals by replacement.

The interstitial glass varies in colour from a light brown[57] to a dense black. The black glass appears to be opaque but high magnification shows it to be a colourless glass densely crowded with black dust. Intermediate varieties have a brownish tint and often carry microlites of iron-ore and perhaps also of felspar and augite; in cases the iron-ore microlites are sometimes arranged on a gridiron plan. Specimens with light brown glass are on the whole rather finer in grain than those with black glass. Judging from the order of crystallisation of the rock constituents, the glass should have a composition corresponding to a mixture of augite and magnetite; that it is hydrous is indicated by the uniformly high water content found in all analyses of the rocks, and that the water is original is deduced from the fresh appearance of all the minerals present. The amount of glass present varies from 0 to 20 per cent., and is rarely more than this. The alteration products of the glass are palagonite and its brown or orange variety, chlorophaeite, celadonite ("green earth") and chabazite. The black glass readily decomposes and increases the vesicular appearance of the rock.

Olivine, when present at all, is not plentiful. It is rarely fresh except in some of the dolerites, especially those of the dykes and sills, but is most frequently represented by pseudomorphs. When present, it was the first to crystallise, and may frequently be seen encroaching upon or sometimes completely enclosed within the labradorite phenocrysts. The pseudomorphs may consist of red brown iddingsite, rich green delessite, pale green serpentine or an isotropic substance which is perhaps a cryptocrystalline form of delessite; sometimes two or three of these alteration products are seen in the same pseudomorph.

Both oilvine and felspar phenocrysts in some of the lavas show signs of having sunk in the magma and concentrated to some extent in the lower portion of the flow. Some interesting calculations by Fermor lead to the conclusion that the specific gravity of liquid basalt is approximately 2.72 at 1100° C., and 2.50 at 1500° C., and since experiments by Dr. W. A. K. Christie have shown that the labradorite phenocrysts of Bhusawal have a specific gravity of 2.71 (presumably at ordinary temperatures), there may have been a tendency for these

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[57] Washington's "Lemon-yellow" glass is perhaps Chlorophaeite (See L. L. Fermor, Rec. 68, 349 (1934)).

crystals to sink during the earlier phases of cooling[58]; as the dropping temperature approached 1100° C., the possible tendency of the crystals to rise may have been successfully combated in some cases by the increasing viscosity of the cooling magma, the result being the concentration referred to above.

The legitimacy of these deductions depends, of course, on the correctness of the figures arrived at for the specific gravity of liquid basalt. The sinking of the much heavier olivine crystals is readily understood.

The evidence that the density of liquid basalt at some high temperature is less than that, not only of olivine but also of labradorite crystals, and that under favourable conditions of fluidity and quiescence these two kinds of phenocrysts sink in the molten lava, has constrained Sir Lewis Fermor to make some interesting deductions and surmises concerning the magma-reservoir, which may be repeated in his own words: "If then the material in the magma-reservior is at any time quiescent and liquid, an opportunity may be afforded to the porhpyritic labradorites and olivines to sink, for both these are produced intra-tellurically before eruption. The result of the complete sinking of such labradorites and olivines from a given stratum of the molten magma would be to leave a liquid that would solidify on eruption as one of the commonest types of the Deccan Trap lavas, a basalt free from olivine and phenocrystal felspar. The strata through which olivines and felspars are sinking or in which they are for any reason suspended, will on tapping by eruption yield the various olivinic and porphyritic varieties of Deccan Trap basalt." If the lava in the magma-reservoir remained liquid for a sufficiently long time, the result might be the complete sinking of the olivines and labradorites. Sir Lewis then continues: "The process of sinking would tend to effect a separation of these two minerals, the effectiveness of which would be dependent upon the viscosity of the liquid and the vertical distance through which sinking took place. One set of conditions might give us a rock composed of admixed labradorite and olivine, in fact a troctolite, whilst another set might produce a separation of these two minerals into peridotite below and an anorthosite above, and this tendency would be accentuated by the fact that the olivine commenced to crystallise out before the labradorite, as is indicated by the fact that olivine pseudomorphs are often found enclosed in labradorite phenocrysts." The Bhusawal lavas provide no evidence of the existence of intra-telluric augite.

Secondary minerals.—Secondary minerals of various kinds, formed since consolidation, are found in the greatest abundance in some of the flows, especially in the amygdaloidal, and in some of the more earthy and decomposed traps. These minerals not only form the nodules of the amygdaloid but are found lining cracks and

[58] The legitimacy of the conclusion depends, of course, upon what the specific gravity of labradorite would be at high temperatures such as 1100°C. and 1500°C.

hollows, the best formed crystals being always in geodes or cavities, some of which are as much as two or three feet across, and occasionally even larger. The commonest of these minerals are quartz either crystalline or in the form of agate, jasper, bloodstone, opal, etc., stilbite, apophyllite, heulandite, scolecite (poonahlite), laumontite and calcite ; chabazite, ptilolite, chlorophaeite, delessite, celadonite, thomsonite, epistilbite, prehnite, mesolite, lussatite, gyrolite, analcite and okenite also occur but are much less common.[59] Felspar has also been recorded in the amygdales.[60]

The crystalline quartz of the geodes is occasionally, though rearly, amethystine; it seldom occurs in crystals exceeding an inch in diameter, and the larger crystals are not often transparent. The form known as trihedral quartz, in which the terminal pyramid of each crystal consists of three planes instead of six, or in which three planes are very much more developed than the other three, is of common occurrence. The agates occur chiefly in geodes or nodules, large or small. Many are finely banded and, after being coloured by heating, are cut into ornaments; most of the stones cut for the latter purpose are either procured from river detritus or from the Tertiary gravels derived from the denudation of the traps. The siliceous geodes and veins in the Deccan Trap have been the original source of the supplies of agate and carnelian worked in Cambay and exported therefrom. In the Bhusawal lavas Fermor found chalcedony in the form of banded agate to be much commoner than crystalline quartz. Jasper and heliotrope or bloodstone occur chiefly in flat plates which appear to have been formed in cracks, and agate of apparently similar origin is sometimes met with. Stilbite is only less common than quartz ; one magnificent variety consists of large orange or salmon coloured crystals, often two or three inches in length, usually compound or in sheaf-like aggregates, but occasionally in large flat prisms terminated by a four-sided pyramid. Of all the Deccan Trap minerals apophyllite is perhaps the most attractive ; the crystals generally, and especially when of large size, are four-sided prisms with terminal faces, closely resembling the cubical crystals of the isometric system. The colour of the Deccan apophyllite is usually white, more rarely pink or green ; some crystals are perfectly transparent, and when inserted on a mass of orange stilbite, as they occasionally are, a magnificent mineral association is the result. Some specimens of apophyllite are as much as three or four inches across. Deserving also of notice are the occasionally seen, beautiful, long, acicular crystals of scolecite with exquisitely formed pyramidal terminations, and the fine crystals of white heulandite. In the Bhusawal area calcite is abundant in certain localities and sometimes large and clear enough for optical purposes. Calcite is the only mineral whose origin may have been meteoric instead of magmatic, and whose deposition may have taken place from percolating waters at ordinary temperatures.

[59] W. A. K. Christie, Rec. 56, 199 (1925). Holland has shown that "*histopite*" is but a mixture of calcite, glauconite and other minerals such as celadonite and heulandite (Rec. 26, 170-171 (1893).

[60] C. S. Pichamuthu, Q. J. Geol. Min. & Met., Soc. Ind. Vol. 7, 157 (1935).

The formation of the vesicles and geodes of Deccan Trap is ably described by Sir Lewis Fermor.[61] That these cavities were formed shortly after eruption seems indicated by the chilled edges they often show. That they were blown by steam is highly probable in view of the high percentage of water; this excess of water is shown not only by the presence of hydrous substances in the form of zeolites, opal, chalcedony and primary basaltic glass, but also by analyses of even the non-vesicular lavas, and also by the fact that no other volatile constituent of importance has been detected in the rocks.

From the presence of certain striae on the crystals of heulandite, recording evidence of former structures characteristic of particular stages of hydration, Fermor deduces that this mineral must have been formed at a temperature somewhere between 240° C. and 370° C. Arguments based on experiments by Stocklossa upon the hydration of partly dehydrated chabazite, lead to the conclusion that the chabazite of the Bhusawal traps was formed as an anhydrous mineral at a temperature of over 280° C. Such considerations support the presumption that the zeolites and other secondary products excepting calcite, were of late magmatic origin.

Chemical Composition.—Analyses of the traps show an extraordinary uniformity in chemical composition. This could not be better exemplified than in the following analyses of four of the Linga flows made by M. Raoult, two of them basalts almost devoid of olivine, the other two, olivine dolerites. As noted by Fermor, whether the lava consolidated as an olivine dolerite or as a basalt does not seem to have depended upon the chemical composition, but rather upon differences in the conditions of consolidation.[62] The table also shows the mean of these four analyses of lower traps, the mean of four analyses by H. S. Washington of lower traps from four separate districts of the Central Provinces, and an analysis by the same observer of the Rajahmundry trap.

[61] Rec. 58, 209 (1925).
[62] Rec. 68, 357 (1934).

Table showing the results of chemical analysis of traps.

	Lower Traps							Upper Traps
	Flow 1—Chhindwara (Raoult) Olivine-dolerite, Goreyghat	Flow 2—Chhindwara (Raoult) Olivine dolerite Kulbehranala	Flow 2a—Chhindwara (Raoult) Basalt, Bisapar Khurd	Flow 3—Chhindwara (Raoult) Basalt, Shikarpur Quarry	Mean of 4 analyses—Chhindwara d., C.P. (Raoult) C.P.	Mean of 4 analyses—four districts of the C.P. (Washington)	Rajahmundry Trap (Washington)	Mean of 3 analyses—Bombay Presidency (Washington)
SiO_2 . . .	49·06	49·08	49·20	49·78	49·28	49·51	49·90	51·69
Al_2O_3 . . .	11·66	11·79	11·50	11·80	11·69	13·05	11·98	14·72
FeO . . .	3·26	2·98	3·11	2·83	3·04	3·06	4·55	2·83
Fe_2O_3 . . .	11·31	11·71	11·35	11·86	11·56	10·39	9·83	10·87
MnO . . .	0·22	0·22	0·24	0·24	0·23	0·22	0·15	0·11
MgO . . .	5·01	4·79	4·91	5·13	4·96	5·71	5·89	4·18
CaO . . .	10·44	10·54	10·60	10·36	10·49	10·18	9·80	8·20
Na_2O . . .	2·27	2·46	2·55	2·75	2·51	2·25	2·23	3·25
K_2O . . .	0·70	0·78	0·63	0·63	0·68	0·51	0·47	0·93
H_2O+ . . .	1·82	1·40	1·70	1·08	1·50	1·99	0·89	2·01
H_2O- . . .	1·08	0·80	0;92	0·52	0·83	0·32	0·33	0·58
TiO_2 . . .	3·20	3·18	3·24	3·20	3·23	2·3	3·76	0·63
P_2O_5 . . .	0·37	0·33	0·25	0·28	0·31	0·37	0·21	0·42
Total .	100·40	100·07	100·30	100·46	100·31	99 92(1)	99·97	100·42

(1) Including 0·02 of SO_3.

Folding in the traps.—One of the most remarkable characters of the Deccan Traps is their persistent flatness or near approach to horizontality throughout the greater portion of their area. This is conspicuous throughout the Western Ghats, over the whole of the Bombay Deccan, from Khandesh to Belgaum and Sholapur, throughout southern Berar and the northwestern portion of Hyderabad State, in many parts of the Satpura range between the Narbada and Tapti, and on the Malwa plateau north of the Narbada. In several places where exceptions occur, as in the western Satpura and Rajpipla hills and in Bombay Island, the disturbance has effected at the same time younger beds of sedimentary origin. In the Chhindwara district Dr. Fox has shown that the traps are warped into very gentle anticlines and synclines, but in such cases it is difficult to decide whether these irregularities are due to subsequent tectonic movement, or to the adjustment of the flows at the time of their effusion to the underlying Archaean peneplain.[63] Fermor and Fox, however, record numerous examples of dips ranging up to 15°, and in rare cases even more, in the traps of Linga, and attribute them to tectonic anticlines and synclines with axes directed W.N.W.—E.S.E.[64]. In the Islands of Bombay and Salsette, and probably farther north on the same line of coast, the traps have an inclination of from 8° to 10° to the westward[65]. These islands are separated from each other and from the mainland to the north by tidal creeks and alluvial flats, whilst the expanse of water forming Bombay harbour lies between them and the mainland to the eastward.

In the islands of the harbour, and on the hills between Thana and Kalyan north of the harbour, the same westwardly dip is displayed but further to the eastward, from Kalyan to the Western Ghat range, the traps are horizontal. The only departure from horizontality to be seen in the lava flows of the Deccan is frequently no more than may be due to the lenticular form of the beds. Usually there is a very low dip discernible and where this is constant over large areas, as it sometimes is, it may represent the original inclination at which the flows were consolidated.

Faulting in the traps.—There is definite evidence in the presence of faulting to show that both the flows and the intrusive dykes of the traps have been disturbed since their formation. The traps of Bombay Island, for example are believed to have been affected by a fault of considerable size, with a downthrow to the east[66], and there is in fact some reason for concluding that the great scarped face of the Western Ghats, consisting as it does for over 300 miles of Deccan Trap flows, is the result of a gigantic fault. Several instances of block-faulting of small throw are recorded in various parts of the

[63] Gen. Rep. Rec. 42, 90 (1912).

[64] An ingenious attempt to arrive at the dip of the trap beds by measuring the inclination of the layers of chalcedony in the onyx of the geodes, gave somewhat dubious results, the angle being in all cases extremely small ½° to 2°) Rec. 47, 110 (1916).

[65] Gen. Rep. Rec. 54, 47 (1922).

[66] Rec. 54, 13, 126 (1922)

Central Provinces[67]. The strike of the faults in Chhindwara is approximately E.N.E.—W.S.W., a direction which seems to indicate that the movement which caused these fractures tended to follow pre-Trap trend lines[68] and to have been but a further phase of the disturbance which had let down the Gondwana sediments into their local basins. The Ellichpur fault, which lies at the southern foot of the Gawilgarh hills, is a post-Trap fault with a large downthrow to the south ; the Chhindboh fault, occuring along much the same line of strike as the Ellichpur, is thought to be a pre-Trap dislocation along which further displacement has taken place during the Deccan Trap period itself[69].

It is probable that the faulting during and after the Deccan Trap period, like that of the Gondwana basins, is attributable to an upward warping of the great rigid shield of the Indian Peninsula, caused by the Himalayan movement. The more or less E.—W. faulting in the Trap is readily explained by such an hypothesis, and even the faulting with more N.—S. directions might well be due to irregularities in the strain produced by this widespread movement and its accompaniments in Burma and Northwest India.

Both Medlicott and Crookshank come to the conclusion that the Trap areas in the Narbada valley have been greatly disturbed, and it seems possible that the river, in some measure, owes its alignment to the presence of a large E.—W. fault or fissure.

Thickness of the lava beds.—The separate beds of lava vary greatly in thickness. Contiguous flows may sometimes be distinguished by textural or mineralogical differences, by a finer grain produced by atmospheric chilling, or by intervening belts of oxidation and weathering[70] ; where this cannot be done, as is frequently the case, two or more beds of similar appearance may easily be confounded and measured as one. In Kathiawar, Fedden counted 8 superimposed flows in a scarp of 320 feet south of Chotila[71] ; at Bhawanagar in the same peninsula the average thickness of 6 flows is 83 feet[72]. In Ahmedabad 18 exposed flows average 51 feet. Some borings in Kathiawar and the Ahmedabad district passed through no less than 48 flows, many of them highly vesicular, averaging about 39 feet in thickness, besides several agglomerates and two Inter-Trappean beds[73]. The average thickness of the Bhusawal traps in East Khandesh is between 40 and 46 feet. In the Sausar *tehsil* of Chhindwara, Crookshank identifies 15 flows, the average thickness of a single flow being 75 feet, the maximum 120 feet and the minimum 40 feet[74], in north Chhindwara the same observer found that while near Kodali (Kundali) the average thickness of the six lowest flows is about 56 feet, with a maximum of

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[67] Gen. Rep. Rec. 45, 128 (1915) ; Gen. Rep. Rec. 44, 135 (1914).
[68] Gen. Rep. Rec. 60, 94 (1927).
[69] H. Crookshank, Mem. 66, 284 (1936).
[70] L. L. Fermor, Rec. 58, 111 (1925).
[71] Mem. 21, 92 (1884).
[72] Rec. 58, 114 (1925).
[73] Gen. Rep. Rec. 66, 18 (1932).
[74] Gen. Rep. Rec. 60, 93 (1927).

85 and a minimum of 40 feet, thirty miles southwest, near Belkheri the three lowest flows measure 110, 130 and 90 feet[75]; in north Seoni, Burton distinguished 9 flows having a total thickness of 775 feet and separated from each other by Inter-Trappean horizons.[76] In one part of the Mandla district Hallowes found that the middle 5 out of 7 flows total 490 feet[77], but in other parts the middle 6 of 8 flows average about 108 feet each.[78] In the country southwest of Hyderabad city some 5 flows have been distinguished, varying from 40 to 65 feet in thickness and separated from each other by Inter-Trappean layers of brown or green chert, creamy white limestone, green earth and dark red ferruginous bole.[79] Some detailed mapping in the Linga area of Chhindwara by Fermor and Fox has yielded many interesting results. Here five flows are recognisable, mostly separated from each other either by the green earth or by Inter-Trappean sediments frequently with fresh-water fossils.[80] Omitting the uppermost flow which has suffered some erosion, the other four, commencing with the lowest, measured 60 feet; 45 feet; 90 or 110 feet; and 70 feet. The lowest flow abutted against a ridge of granite and was overlapped by the succeeding flow. Most of the Linga flows have been recognised in another part of the Chhindwara district, 25 miles away,[81] and are probably continuous into Nagpur; they have all been recognised in eastern Betul where they average only 15 or 20 feet and are overlain by flows just as thin.

Distribution of vesicles.—Many of the more amygdaloidal beds of trap appear to be made up of several small flows from six to ten feet thick; each of these is distinguished by being highly amygdaloidal above, less so in the middle, and traversed in its basal portion by long cylindrical pipes filled with zeolite. It is easy to understand that the upper portion of a lava flow, having been more vesicular originally than the lower portion, would be characterised by the prevalence of amygdales; the vertical pipes or tubes must also originally have been filled with air or vapour, which was probably expelled from the underlying stratum by the heated mass flowing over it, and prevented from further upward progress by the solidification of the lava.

The following is a typical section of one of the Linga flows where thick enough to display the succession of characters[82] :—

Surface.—Vesicular basalt with amygdales of quartz, chalcedony, banded onyx and calcite, and with surface cracks and furrows;

6.—Roughly columnar basalt, with pipe-like vesicles, some of which are filled with quartz and calcite and are

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[75] H. Crookshank, Mem. 66, 282 (1936).
[76] Gen. Rep. Rec. 45, 131 (1915).
[77] Gen. Rep. Rec. 45, 128 (1915).
[78] Gen. Rep. Rec. 47, 37 (1916).
[79] Gen. Rep. Rec. 55, 39 (1923).
[80] Rec. 47, 86 (1916).
[81] Gen. Rep. Rec. 59, 80 (1926).
[82] Rec 47, 99 (1916).

surrounded by fine-grained basalt containing much interstitial glass ;

5.—Open-textured doleritic basalt with large cavities lined with chalcedony, with quartz crystals terminating in the drusy cavities of the geodes ;

Middle 4.—Passage from compact ophitic dolerite to rough-looking, granular dolerite ;

3.—Texture changing from granulitic or intersertal to ophitic ;

2.—Texture grading to that of a true dolerite with olivine ;

Base.—Fine-grained basalt with abundant phenocrysts of felspar, sometimes vesicular and zeolitic, but frequently altered more or less completely to green earth.

A typical amygdular flow in north Chhindwara, according to Crookshank, is about 75 feet thick, and may consist of a central non-vesicular portion 20 feet thick ; amygdales visible to the naked eye are concentrated in a zone about 6 feet thick near the base, and in another nearly 50 feet thick at the top. A similar concentration of vesicles in the upper and lower layers is noted by Fermor in the unexposed lavas at Bhusawal in Khandesh ; here the middle portion may be non-vesicular except where the flow is very thin when it may be vesicular throughout.[83] This basal vesicularity, which is usual though not invariably present in the Bhusawal lavas, may be attributable to the moist surface over which the lava flowed, but Fermor prefers to assume that these basal vesicles, like those along the upper margin, are due to water indigenous in the trap itself. The apposition of the vesicular base of one flow against the vesicular top of the flow below makes it difficult to detect the position of the junction plane, unless there are textural or mineralogical differences between the two successive flows that make their mutual separation easy ; in some cases the surface of the lower flow may be fine-grained as a result of chilling, or reddened by oxidation or in rare cases by a thin layer of red clay. If a flow be of considerable thickness, the interior may be hard and columnar, but even in the thickest flows occasional vesicles may be found at any stratum of the interior[84]. That the gaseous substance primarily responsible for the formation of the vesicles was steam is suggested by the presence of many hydrous minerals within the lavas. Sir Lewis Fermor is inclined to think that the water in these hydrous minerals is due not so much to meteoric sources active after the consolidation of the lavas, as to water originally present in the magma, in which case the formation of these hydrous minerals might well be regarded as a late magmatic process, operating at various stages during cooling. Indubitable evidence of the presence of a certain amount of water in the magma is afforded by the presence of water in the fresh primary glass found in the lava.

[83] Rec. 58, 110 (1925).

[84] L. L. Fermor, Rec. 58, 110-111 (1925).

The floor of the Traps.—That the same flows should have spread over so large an area as they cover in Chhindwara, Nagpur, Seoni and Betul, indicates not only that the lavas were extremely fluid but that they were assisted by a gradient however slight in degree. At the same time the absence of Archaean inliers in the main Trap areas suggests that the relief of the pre-Trappean surface was of a low order; in the Linga area the surface consisted of a slightly undulating plain with low hillocks and such slight depressions as are seen today in the crystalline country west of Chhindwara.[85] Since the contraction of a cooling basalt must be greatest where the depth of lava is greatest, *i.e.*, over buried valleys, Fermor and Fox come to the interesting conclusion that the surface relief after the eruption of a flow would tend to be a faint copy of the relief which obtained previous to the flow; denudation acting during a prolonged Inter-Trappean interval would accentuate this relief, and there would thus be a tendency to perpetuate the pre-Trappean drainage lines.

In the Kanhan valley of Chhindwara the Archaean floor of the traps has been found to slope to the extent of about 675 feet in 13 miles, downwards from north to south.[86] Aneroid readings taken at the base of the Trap at various points seem to indicate that the Mahadeo range, now largely covered with trap was a feature of pre-Trappean topography. In the region south of the Morand river, on the northern slopes of the Mahadeo hills, gradual rises and falls in the level of the base of the flows, amounting in some cases to 400 feet in a mile, have been repeatedly observed by Crookshank, and are thought to reflect the pre-Trappean topography.[87] The same region, however, affords instances of rapid change in level. Near Sua Am there is a sudden dip in the base of the trap about 350 feet in depth, representing probably the infilling of an old valley in the underlying Bijori rocks[88]; near Morghat, the rocks forming the floor of the trap had been eroded into a system of small strike ridges and valleys, the former being now exposed, while the hollows between are filled with basalt.[89] The basal flow of Deogarh hill and the underlying Lameta sediments in the Chhindwara district occupy another old river valley at least 50 feet deep. Admirable examples of the same thing are seen between Bhopal and Hoshangabad, where the Deccan Traps rest upon an extremely uneven surface of Vindhyan rocks.[90] In the south Maratha country also the floor of the traps is said to be very irregular. In Jhabua State there are places where the basalt rests on a floor of ancient Aravalli rocks at a lower level than the surrounding Bagh sediments.[91] In southern Rajputana, according to Dr. Heron, the land surface over which the trap was poured appears to have been very similar to that of the present day, a country of low hills of gently dipping Jiran sandstone, with

[85] L. L. Fermor & C. S. Fox, Rec. 47, 88 (1916).
[86] Gen. Rep. Rec. 43, 31 (1913).
[87] Mem. 66, 276 (1936).
[88] Mem. 66, 277 (1936).
[89] Figure 9, Mem. 66, pt. 2.
[90] W. T. Blanford, Mem. 6, 240, (1869).
[91] Gen. Rep. Rec. 37, 46 (1908).

intervening valleys occupied by the Binota Shales in the anticlinal folds of the sandstone, and by the Nimbahera Shales in the synclines. These ancient valleys were, and to a large extent still are, entirely filled with the trap sheets, through which the Jiran sandstone projected as low ridges, now reduced to broken lines of outcrops.[92]

Some interesting striations noticed by Crookshank on the surface of the Gondwana sandstones of the northern slopes of the Mahadeos especially between the Hard river and Kodali, are believed to have been caused in some way by the scouring movement of a basalt flow ; in nearly every case these scratches are perpendicular to the main faults and dykes of the region.[93]

Crater-like fumaroles.—Occurring on the recently exposed surface of the lowest flow seen in the bed of the Kulbehra river opposite Shikarpur,[94] scattered over a distance of about 1,600 feet, are some 20 curious hollows or craterlets. These depressions, which, on this small scale, have not been noted in any other part of the immense Trap area, are mostly circular or oval in shape, and vary in diameter from 3 to 20 feet, with walls rising from 1 to 3 feet above the surrounding lava surface. Whereas the lava both outside and inside the hollows is usually very vesicular, that composing the walls, which may be from 1 to 3 feet thick, is an almost non-vesicular variety, more resistant to weathering, and sometimes showing a roughly columnar structure of radial disposition. In a few cases lava seems to have issued from the craterlets ; in one case lava has flowed from outside into the craterlet. They appear, in the main, to be the results of the escape of steam and hot gases, the rims of burst bubbles of vapour derived from the still liquid middle layer of the flow and ejected after the upper and lower layers had reached a viscous semi-solid consistency.

Slickensides of a similar nature thought to have been produced by mobile lava upon a congealed lava surface in a dyke are reported from Auckland, New Zealand.[95]

The Lonar Lake.—Of somewhat similar character but on an immensely greater scale is the curious crateriform lake, situated in the interior of the Indian peninsula, near the village of Lonar, in the Buldana district of the Central Provinces, close to the northern border of the Nizam's territory, about half-way between Bombay and Nagpur, and hemmed in by an amphitheatre of well-wooded cliffs.

The surrounding country for hundreds of miles consists entirely of Deccan Trap and it is in this rock that the nearly circular hollow lies. Towards the end of the dry cold season the water is not more than two feet deep. The bottom is covered with black mud and the lake itself is surrounded by a very gentle shelving ring of the same deposit.[96] Outside this is another annular strip of ground covered

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[92] Mem. 68, 114 (1936).
[93] Mem. 66, 283 (1936).
[94] L. L. Fermor & C. S. Fox, Rec. 47, 120 (1916).
[95] J. A. Bartrum, N. Z. Journ. Sci. & Techn. 10, 23-25 (1928).
[96] T. H. D. La Touche and W. A. K. Christie, Rec. 41, 272 (1912).

with coarse grass which may be submerged in seasons of exceptional rainfall. From the edge of this strip the ground slopes up more rapidly on all sides outwards to the base of a surrounding wall of rocks, the surface of which in its turn slopes regularly upwards at an angle of about 40° and rises to an even height of about 300 feet above the lake. The diameter of the hollow thus formed by this wall is about 1¼ miles across the bottom. The drainge channels into the lake, with the exception of that fed by a spring near Lonar village, are dry except when rain is actually falling, and are arranged in remarkable symmetry round the encircling wall.

The surface of the surrounding plateau slopes gently away from the edge of the hollow, corresponding with a very gentle quaquaversal dip in the lava, except on the northeastern side where the village of Lonar stands on slightly higher ground. A ring of low, mound-like elevations, strewn with loose blocks of lava, stands upon the very edge of the crater. This raised rim was at one time supposed to represent relics of material ejected from the hollow, but La Touche has shown that the blocks of lava composing the rim have been weathered out into such *in situ*.

Two principal theories have been advanced to explain the mode of formation of the Lonar hollow. According to one view, it was the result of volcanic explosions. Since the blocks of lava forming the rim cannot be regarded as parts of the ejectamenta, the major part of the latter must have been reduced to fine dust and thus scattered over the surrounding country and removed by denudation. There are many serious objections to this theory, the most important of which are the following. There is no sign of any eruption and no indication of a central pipe of funnel, nor are there any dykes in the surrounding rocks. Another objection which has been advanced is that, if the lake had been formed in the present surface of the country which is the result of ages of denudation of the Deccan Trap flows, such explosions would have to be regarded as of comparatively recent origin; though Recent or Tertiary outbursts of this character are deduced in upper Burma, such an explosion or series of explosions in comparatively recent times is unmatched elsewhere in the whole of the Peninsula. It seems highly probable, however, that the Lonar hollow, like the much smaller and much more easily effaceable hollows in the Kulbhera river described above, was formed during one of the final solfataric phases of the Deccan Trap disturbance, and owes its preservation as a physiographical feature to the regularity and uniformity of the erosion subsequently suffered by its homogeneous walls.

La Touche has put forward an ingenious modification of an older subsidence theory which removes most of the above difficulties. He suggests that, during a phase of the Deccan Trap period subsequent to the extrusion of the lava flows forming the circular wall of the lake, large blister of steam or molten lava formed beneath the surface of these solidified lavas and naturally assumed a circular form. This steam or molten material then finding an outlet elsewhere caused the blister to collapse and let down the overlying rocks in the

form of a circular block along a kind of circular fault. It is even thought that indications of such a fault are to be seen in the influx of fresh water from springs on all sides of the basin in somewhat larger quantities than would be expected, were faulting absent. The water of the lake is salty and crude soda has been obtained therefrom for centuries (See p. 2008).

Total thickness of the Deccan Trap formation.—The mantle of Deccan flows is thickest in western India and is probably considerably greater than 6,000 feet in the neighbourhood of Bombay, where the upper limit is not seen. Matheran hill shows a section of over 2,500 feet and probably more than this has been removed by denudation. The total thickness of the lavas under Mahabaleshwar on the Western Ghats may well be over 5,000 feet[97], and something like 4,000 feet are exposed in these hills where they overlook the Konkan. It is highly probable that near Surat and Baroda the Trap may have been even thicker than near Bombay, but the upper portions have been greatly denuded, and it is extremely difficult here, as in most other places, to estimate the total thickness with any accuracy. From the Bombay-Surat-Baroda area the rocks gradually thin out in other directions. In Cutch the traps are about 2,500 feet thick, whilst in Sind they have dwindled to two contiguous flows totalling less than 100 feet thick. In the extreme south of the Trap area, near Belgaum, their thickness has been estimated at from 2,000 to 2,500 feet. Sections of 2,000 feet are seen in the scarp of the Melghat plateau facing the Purna valley of Berar. Over much of the Central Provinces the total thickness varies from 200 to 700 feet.[98] The traps of that part of the Mahadeo hills comprising eastern Betul, southern Chhindwara and southern Seoni, together form a mere crust, rarely exceeding a total of 300 feet, and built up of the same flows as those distinguished in Linga. In other parts of this range the combined thickness is very much greater; in the high tracts north of Amarwara and the adjoining parts of Seoni it swells to 1,200 or 1,500 feet. On the plateau of Amarkantak, at the eastern extremity of their main area the traps are about 670 feet thick, with a capping of laterite which is some 3,500 feet above sea level; in this venerated hill the trap rests upon Lameta limestone, which succeeds about 100 feet of Talchir beds lying upon a rising floor of gneiss.[99] Farther east, in the outlier on the Main Pat in Sarguja they are not more than 300-400 feet, whilst to the southeast, near Rajahmundry, they are represented by a thin outlier in which from 100 to 200 feet of basalt may be exposed. Throughout the greater portion of this area no higher beds, except laterite or post-Tertiary deposits, are found resting upon the trap lavas, and it is impossible to calculate what their original development may have been.

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[97] C. S. Fox, Rec. 58, 86 (1925).

[98] In Betul between 400 and 500 feet (Rec. 43, 36 (1913)) ; on Mate Pahar Pipardol in Nagpur less than 450 feet (Rec. 67, 68 (1933)).

[99] Gen. Rep. Rec. 45, 111 (1915).

INTER-TRAPPEAN BEDS.

Two principal horizons.—The Inter-Trappean beds have been found in two distinct portions of the Deccan series, the first being close to the base throughout the greater part of the enormous circuit of the volcanic area, and the second in the highest portion of the traps which, for reasons which will appear later, are believed to be restricted to the coast in Bombay Island and the immediate neighbourhood. The following is a rough classification of the whole formation, the thickness of the two upper stages being little more than guesses, described as minimum estimates of the vertical extent of the series where fairly developed:

3. Upper traps, with numerous beds of volcanic ash and the Inter-Trappean sedimentary deposits of Bombay . .	1,500 ft.
2. Middle traps, with ash beds numerous above but less frequent towards the base, and not known sedimentary beds . .	4,000 ft.
1. Lower traps, with the Inter-Trappeans of Nagpur, the Narbada valley, etc., volcanic ash being of rare occurrence or wanting	500 ft.
Lameta or Infra-Trappean beds	20-100 ft.

(a) LOWER INTER-TRAPPEANS.

Position.—First to be considered are the Lower Inter-Trappeans. These beds, in the form of thin bands of chert, limestone, shale or clay, often abounding in fossils of fresh-water or terrestrial origin, are found interstratified with the lower traps almost throughout the great Trap area and especially in parts of the Central Provinces, northern Hyderabad, Berar, and the States north of the Narbada valley; these sedimentaries occur near the base of the formation, in no case so far as is known at a greater height than from 300 to 500 feet above the local base.

"Pseudo-Inter-Trappeans".—Simulated Inter-Trappeans are described by Crookshank in north Chhinndwara, where small masses of stone have been separated from the main mass of Gondwana sandstone by sills of Deccan dolerite which have intruded between the sandstone and the overlying flows. Some doubt also attaches to the mode of origin of the green clay or "green earth", which is frequently seen as an Inter-Trappean layer, sometimes associated with brownish and cream-coloured clays. The green material is most probably the result of decomposition after the formation of both the enclosing beds of trap, due to the percolation of meteoric water along the plane between them, which was not only a plane of weakness but may have been occupied at the time of such percolation by a certain amount of sub-aerially formed sediment. Where these intercalated clay bands are entirely red in colour, we have firmer grounds for interpreting them to be old land surfaces; as a rule these, with their characteristically sharp boundaries, do not co-mingle with the aqueous Inter-Trappean sediments which seem to have been deposited in numerous isolated small pools.[100]

[100] Gen. Rep. Rec. 35, 56 (1907).

Lithological character.—One form of the Inter-Trappean bands consists of a dark or pale grey limestone, often earthy or impure, but rarely gritty like the characteristic Lameta bed. As a rule this limestone, like most rocks lying beneath the trap, has been more or less completely silicified by percolating waters ; perhaps the commonest and most conspicuous type of Inter-Trappean is a dark, compact, cherty rock—a kind of lydian stone. In the Linga area of Chhindwara, the Inter-Trappean strata vary from a brown chert or dark siliceous rock to soft, lavender-coloured, calcareous shale. Here the siliceous forms are clearly the products of secondary silicification, the original sediments having been the calcareous shale and in all probability a fossiliferous limestone ; the fossil-bearing rock varies from a chert full of *Bullinus prinsepii* Sow. to a calcareous rock composed almost entirely of *Limnaea* and *Paludina*.[101] Frequently the sedimentary bed includes volcanic detritus, and may be composed almost entirely of such material. Fragments of pumice, for instance, may be seen embedded in the limestone, or numerous pieces of volcanic ash in the olive clays.[102] In the Morand river region of Betul, a band of Inter-Trappeans, sometimes 20 feet in thickness, traceable for at least a mile, is composed of black and buff shales, with shell beds, in all of which are embedded numerous fragments of volcanic ash.

As a rule, the sedimentary beds interstratified with the lava flows are distinguished from those believed to underlie the whole volcanic series by the absence of pebbles and sand, but occasionally, though rarely, sandy and even pebbly beds are found at some distance above the base of the trap. In the south Maratha country, in fact, most of the Inter-Trappean beds are sandstones and conglomerates. In north Chhindwara, Crookshank records the presence in Inter-Trappean bed low down in the Trap series of pebbles of quartzite and crystalline limestone derived from the floor of ancient crystalline rocks, as proof that the basal flows of this region had not completely covered the hills of crystalline rocks at the time the Inter-Trappean sediments were deposited, and that such pebbles were washed over the surrounding basalt plain in one of the intervals between the flows.[103]

Another interesting form of Inter-Trappean accumulation is that described from the country north of the Narbada and south of Chhota Udaipur, on the banks of the Karo, a tributary of the Hiran river.[104] The lower beds of the Trap series here include conglomerates, sandstones and sandy grits, sometimes resting on a bed of basalt, but occasionally on the Bagh Cretaceous sediments which underlie the volcanic formation.[105] Occasionally the sandstone of conglomerate is composed chiefly of detritus derived from the meta-

[101] L. L. Fermor and C. S. Fox, Rec. 47, 101 (1916).
[102] H. Crookshank, Mem. 66, 287 (1936).
[103] Mem. 66, 198 (1936).
[104] W. T. Blanford, Mem. 6, 327 (1869).
[105] Finding these deposits on the Bagh beds, Bose classified them as Lameta (Mem. 21, 46 (1884)) but their character and stratigraphical position elsewhere show that eruptions had occured before their accumulation.

morphic rocks, but volcanic fragments, usually in the form of rolled pebbles of basalt, can always be found, and in many places the bed becomes a mass of rolled volcanic fragments, often mixed with unrolled scoriae. At times indeed, the rock is a conglomeratic ash, in which rolled fragments of metamorphic rocks and of basalt occur together; at others it is an agglomerate with angular fragments of basaltic rocks scattered in the matrix and associated with similar fragments and blocks, some of them a foot or so in diameter of more or less baked Nimar Sandstone.[106] Hornblende and pyroxene crystals have been found in these conglomeratic ashy beds, which are in some places as much as 200 feet thick. In some instances the conglomerates appear to have accumulated in hollows such as river beds; be this as it may, the abundance of rolled pebbles and boulders of trap is important as a proof that denudation took place in the interval between successive lava flows.

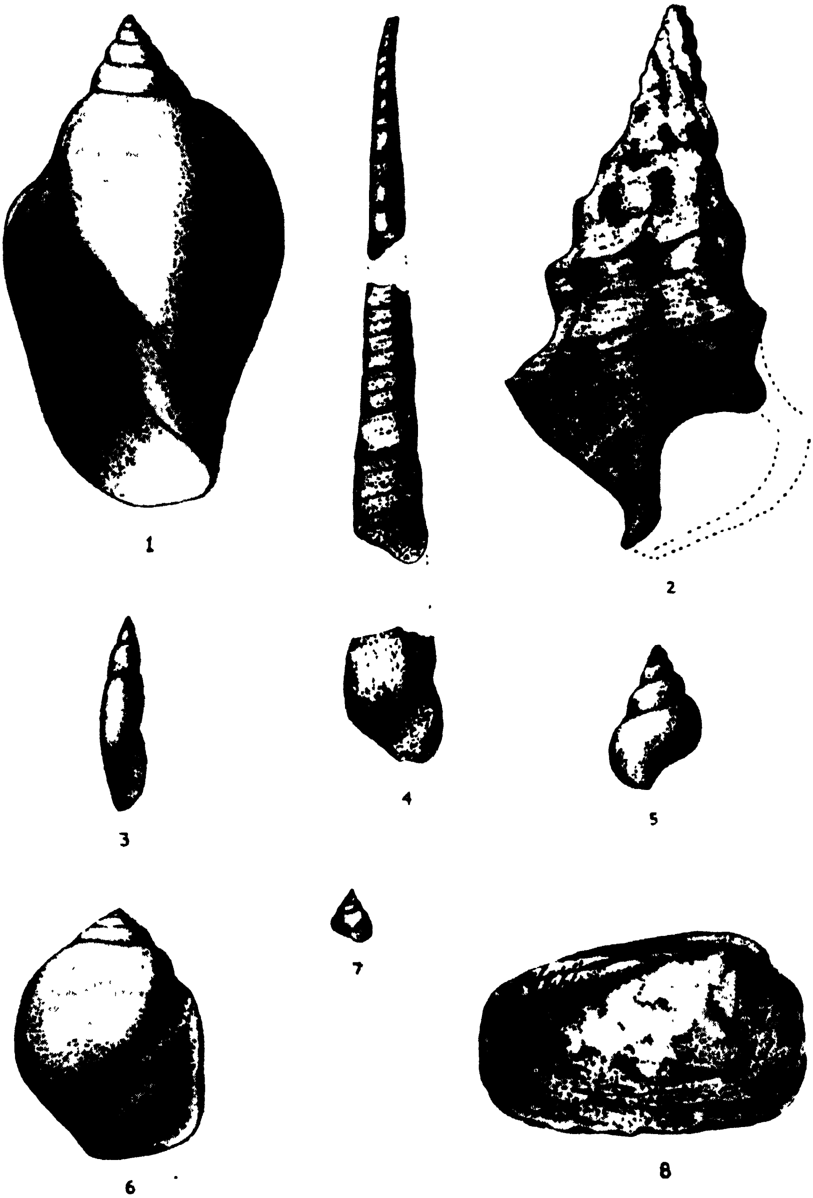
Thickness and mode of occurrence.—With the exception of the examples just described, the Inter-Trappean bands rarely exceed 20 feet in thickness and are frequently reduced to a few inches. Typically they occur in long broken outcrops, contouring the hills in the way peculiar to a thin horizontal stratum; these outcrops seldom continue beyond a mile or so, and are often reduced to intermittent residual blocks of partly or completely silicified limestone.[107] At the same time it is rare to traverse any large tract near the base of the traps without finding some sedimentary bands interstratified. Occasionally an intercalation of this kind is found to be much more extensive than usual; one of them in Sohagpur, east of Jubbulpore, has been traced for nearly 20 miles.[108]

In many places two or more sedimentary beds occur at different levels in the same section, the different bands being in some cases dissimilar in mineral character. Thus, at Mekalgandi (Mucklegundy) Ghat in the Sichel hills, south of the Penganga river, on the old road from Nagpur to Hyderabad, a locality famous as being one of the first at which Inter-Trappean fossils were detected by Malcolmson, the following beds are observed in section:—

7. Trap.
6. Cherty bed containing *Unio*, *Cypris*, etc.
5. Trap.
4. Limestone containing *Cypris* and fragments of small mollusca.
3. Trap.
2. Calcareous grit containing broken shells (Lameta Beds).
1. Metamorphic rocks.

It is unnecessary to detail all the localities at which the lower sedimentary Inter-Trappean beds have been observed. They have been noticed in several places in the southern Maratha country; they are commonly found near the base of the trap flows almost throughout the great and irregular line of boundary extending from the Godavari to Rajputana, and they occur even in small outliers such as that at Main Pat in Sarguja; westwards they have been

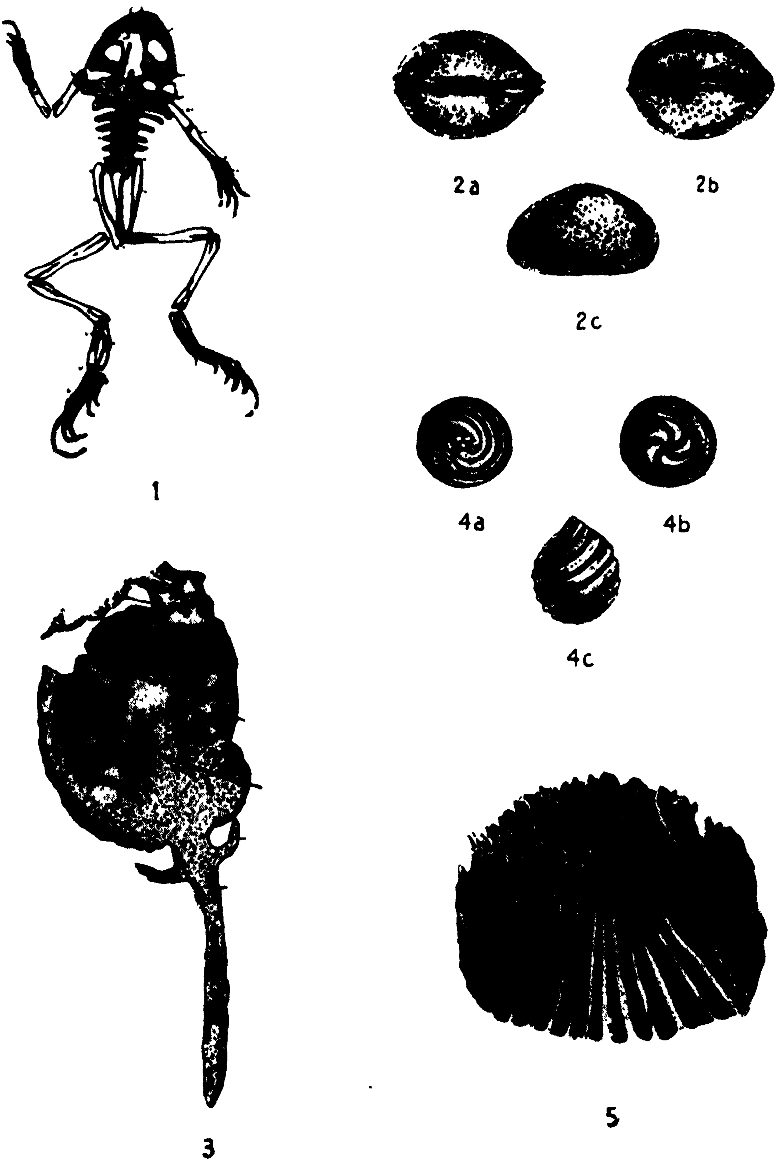
[106] P. N. Bose, Mem. 21, 46-7 (1884).
[107] Gen. Rep. Rec. 35, 56 (1907).
[108] J. G. Medlicott, Mem. 2, 201 (1859).



INTER-TRAPPEAN FOSSILS (A)

1. *Bullinus (Physa) prinsepii* Sow. (X1). 2. *Cerithium stoddardi* Hisl. (X1). 3. *Lymnaea Subulata* Sow. (X1). 4. *Turritella praelonga* Hisl. (X1). 5. *Viviparus normalis* Hisl. (X1). 6. *Natica stoddardi* Hisl. (X1). 7. *Paludina deccanensis* Sow. (X1). 8. *Unio deccanensis* Sow. (X1).

G. S I., Calcutta.



INTER-TRAPPEAN FOSSILS (B)

1. *Oxyglossus pussilus* Owen (X2). 2a. b & c. *Cypris subglolosa* Sow. 3. *Enigmocarpon parijai* Sahni (X4). 4a. b & c. *Chara malcolmsoni* Sow. 5. Nandid fish scale (X18).

G. S. I., Calcutta.

detected at Dohand about 75 miles northeast of Baroda,[109] and still farther west in Cutch.[110]

Organic remains.—The abundance of fresh-water and terrestrial animals and plants in the Inter-Trappean beds has been the principal reason for the comparatively large amount of notice these thin bands of rock have attracted. The mollusca are very abundant and are occasionally exquisitely preserved in the cherty layers, the commonest species being forms of *Bullinus* (*Physa*), especially *B. prinsepii*, and *Lymnaea*, whilst *Unio*, although abundant locally, is of comparatively rare occurrence;[111] the Unionid, *Lamellidens vredenburgi* Prash., from Goraha on the Narbada, has been described by B. Prasad.[112] *Viviparus*, including *V.* (*Paludina*) *normalis* (*Hisl.*), *Melania* and *Valvata* are not uncommon.[113] Recently *Viviparus* (*Paludina*) *decipiens* Oldh. and *Lymnaea obtusa* Oldh., as well as *Bullinus prinsepii* and a species of *Oliva* have been recognised in an Inter-Trappean bed in Hyderabad. Land shells are very seldom found, but have been detected in at least one case.[114] Entomostracous crustaceans are very nearly as common as mollusca, all hitherto found belonging to the genus, *Cypris* (*cyprites*), which is said to have been found in the Purbeck beds of England,[115] but which, according to Zittel, ranges only from the Tertiary to Recent. The genus, *Chlamydotheca*, also reported from the Inter-Trappeans[116] ranges probably from the Jurassic upwards.[117] According to Professor Bonnema, a Tertiary age for these Inter-Trappeans is more probable than a Cretaceous, since allied ostracods still occur living in the neighbourhood of Nagpur.[118] Other remains of animals consist of insects—including mayflies and beetles;[119] fishes and reptiles, all of which are fragmentary. Fish scales from the Morand river beds, according to S. L. Hora, include the following[120] :—

Clupea sp.—(a member of the same family as the Indian hilsa),
Musperia sp.—(a member of the Osteoglossidae which include the largest of the modern fresh-water fishes; species of this family are found today in South America, Africa, Siam, the Indo-Australian archipelago and Australia),
A primitive cyprinid,
A polyacanthid,
A serranid, somewhat like Woodward's Percoid, *Eoserranus hislopi* from the Lametas,
Nandus sp.,
Pristolepis sp.

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[109] A. Rogers, Q. J. G. S. 26, 122 (1870).
[110] F. Fedden, Mem. 9, 58, 240 (1872).
[111] S. Hislop, Q. J. G. S. 16, Pls. 5, 9 & 10 (1860).
[112] B. Prasad, Rec. 51, 368 (1920).
[113] N. Annandale, Rec. 51, 362 (1920).
[114] Mem. 2, 213 (1859).
[115] T. R. Jones, Q. J. G. S., 41, 347 (1885).
[116] T. R. Jones, Q. J. G S., 16, p. 186 (1860).
[117] Proc. Zool. Soc., Lond., p. 90 (1886). The "*Cyprus Strangulata*" of Jones (p. 187, pl. 10, Figures 73a-d) probably belongs to *Cytheridella* (*zoological*) Hft. 44, p. 261, Taf. 17, Fig. 8, 15-18, a recent genus so far known, Rec. 72, 84 (1937).
[118] Proc. Zool. Soc., Lond., 27, 231 (1859).
[119] Rec. 69, 89 (1935).
[120] Rec. 73, 267 (1938).

These identifications also favour a Tertiary rather than a Cretaceous age, and indicate the proximity of the estuary of a sluggish river. Of 13 Coleoptera obtained from the Inter-Trappeans of Nagpur, one, a buprestid, has been named *Lomatus hislopi* Murr., and another, a curculionid, *Meristos hunteri* Murr.[121] Vegetable remains abound, the most abundant being the seed vessels of Characeae, of which one species has been described under the name of *Chara malcolmsoni.* There are many species of fruits, seeds and spores; from Takli near Nagpur, B. Sahni has identified two ovuliferous cones, *Takliostrobus alatus* Sahni and *Pityostrobus crassitesta* Sahni, and from the Chhindwara district the massulæ of an *Azolla* (*A. intertrappea* B. Sahni) with beautifully preserved glochidia, the first record of a water-fern from rocks reported to be as old as Upper Cretaceous,[122] *Palmoxylon hislopi* Rode, *P. kamalam* Rode *and P. sahnii* Rode.[123] Five kinds of wood have been described, including that of monocotyledons and dicotyledonous angiosperms, but leaves are rare. Among the fruits B. Sahni has named the following: the dicotyledon, *Enigmocarpon parijai,* and the monocotyledons, *Amomocarpon sulcatum, Palmocarpon* (*Iriartites*) *takliensis, P. bracteatum, P. trigonum* and *Viracarpon hexaspermum;* the seed, *Sausarospermum fermori,* may be gymnospermous or angiospermous.[124]

All the mollusca and crustacea are fresh-water forms, and with them are associated no marine species except in some beds near Rajahmundry which will be described separately. The insects and plants, with the exception of the fresh-water *Chara*, are of terestrial origin. The general prevalence of the pulmoniferous molluscs, *Bullinus* and *Lymnaea,* indicates that the water was shallow, since these forms live partly at the surface; *Cypris,* too, is commonly found in shallow marshes. Annandale concludes from the presence of the *forma typica* of *Bullinus prinsepii* that conditions were paludine rather than lacustrine or fluviatile, and were those of shallow pools or marches choked with submerged vegetation.[125] Comparing its habits with those of the modern giant ampullariid, *Pachylabra globosa,* we may imagine the *Bullinus* of the Trap period burying itself in the mud when the pools dried up to await the return of the floods, numbers of the species, however, dying in the meantime round the edges of the pools.

The age indicated by part of the fauna might be Maestrichtian, But is not very clear. According to B. Sahni, the flora of the Lower Inter-Trappeans, including those of Nagpur and Chhindwara, which are supposed to be the lowest, corresponds probably to that of the London Clay; this is the original view held by Hislop and others. Sahni finds the palaeobotanical evidence as a whole in favour of a

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[121] A. Murray, Q.J.G.S. 16, 183-184 (1860).

[122] Rec 68, 22 (1934) and Pal. Ind., New Ser., Vol. 11, 103 (1931).

[123] Quart. Journ. Geol. Min. Met. Inst. Ind., Vol. 5, p. 76 (1933).

[124] 25th Ind. Sci. Congr. 30, 31 (1938). The Palms. *Palmoxylon blanfords* Schenk, *P. liebigianum* Schenk, *P. sundaram* Sahni, *P. edwardsi* Sahni, are thought to have come from the Inter-Trappean, but; there is some doubt regarding their derivation (Proc. Acad. Sci. U. P., Vol. 1, Dec. 1931, 140-143).

[125] Rec. 51, 50 (1920).

Tertiary rather than a Cretaceous age, as shown by a preponderance of palms among the angiosperms, by the occurrence of the typically Eocene genus, *Nipa*, and by the presence of the hydropterid *Azolla*.[126]

Water-bearing proclivities.—It is from interbedded tuffs, or from porous Inter-Trappean layers, whether of sedimentary origin or products of decomposition, that water is obtained from wells in the Decan Trap area; such decomposed basalt is known as *moorum*. A still more suitable type of reservoir is found when the basalt lies upon a decomposed layer of older rocks, over an ancient land surface of which the lava had flowed.[127]

Rajahmundry Inter-Trappeans.—We have now to consider some outcrops of trap near Rajahmundry. These are so remote from any other exposure of the Deccan volcanic series, being about 210 miles distant from the nearest point of the great Deccan outcrop, that some doubt as to the identification would remain, despite the similarity of lithological character, had not some of the typical fresh-water fossils of the Inter-Trappean beds been discovered in the Rajahmundry area.

The Rajahmundry outcrops occur on both banks of the Godavari, and consist of an interrupted narrow band of volcanic rocks, chiefly earthy dolerite and amygdaloidal basalt of the usual character, extending altogether for about 35 miles from E. N. E. to W. S. W. From the numerous occurrences of laterite between, it has been suggested that traps once extended over the whole Godavari valley and were continuous between Rajahmundry and Hyderabad, a distance of more than 200 miles, but laterite is not abundant, and so far no possible feeders of the Rajahmundry flows, in the form of trap dykes, have been reported in the intervening trap-less country.[128] It may be regarded as impossible for any extrusion to have flowed from Hyderabad or Nagpur to Rajahmundry, *i.e.*, for a distance exceeding 200 miles, and, unless further discoveries of dykes are made, we must conclude that the dyke which fed the Rajahmundry flows lies underneath the flows themselves and belongs to an outlying eruptive centre.

Traps are seen at Kateru on the left bank of the Godavari just north of Rajahmundry itself, and stretch for rather more than ten miles to the E. N. E., resting upon metamorphic rocks whenever lower beds are seen. On the right bank the volcanic rocks appear in two areas, separated from each other by a small alluvial valley. The larger of these extends for about ten miles westward from Pungadi, and the smaller occurs a few miles still farther west; in these outcrops the beds of the volcanic series rest upon the Tripati Sandstone of the Ellore region . In both cases the strata overlying the trap are Cuddalore sandstones, and all the beds alike have a low dip to the south or southeast. The whole thickness of the volcanic

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[126] Gen. Rep. Rec. 68, 22-3 (1934).
[127] Mem. 32, 84 (1901).
[128] L. R. Rao, Proc. Ind. Acad. Sci. Vol. 4, 217 (1936).

series at this locality nowhere appears to exceed 200 feet, and in places is no more than 100 feet. The Dudkur marine Infra-Trappeans found at the base of one outcrop of the traps, have already been described (p. 1261).[129]

Upon the marine limestone of Dudkur a flow of basalt is superposed, varying in thickness from about 30 to 100 feet. There is an appearance of slight unconformity where the volcanic rock rests upon the sedimentary bed, the surface of the latter being slightly uneven, as if denuded, and its upper fossiliferous zone is occasionally wanting. The variation in thickness of the basalt bed may be due to its having been poured out upon an uneven surface; that the erosion of the underlying sediments can have been only partial, however, is shown by their persistence for a distance between three and four miles, the upper portion alone being locally absent.

The thickness of the lower flow of basalt is not less than 40 feet, and is probably more. Above this flow on both banks of the Godavari lies a sedimentary band, twelve to fourteen feet thick at Kateru where its extent is only about half-a-mile, and from two to four feet thick in the Pungadi direction where it has been traced for about ten miles. This Inter-Trappean bed consists of limestone and marl, portions of which abound in fossils, which are obtainable from numerous quarries; the fossils are difficult to extract from the newly-quarried, argillaceous limestone, but weather out on exposure. Above the fossiliferous limestone of Kateru and separated thereform by 30 or 40 feet of trap is another sedimentary bed in one place, very thin, unfossiliferous and consisting of yellow calcareous shale.

The most marked feature of this Inter-Trappean fauna is the estuarine character.[130] *Potamides,* and its three subgenera, *Tympanotomus, Pirenella* and *Cerithidea,* inhabit only brackish water or estuaries. *Hydrobia* is another estuarine genus, and the fossil which has been called *Hemitoma* closely resembles a species of *Acmaea* found living in creeks in the deltas of Indian rivers.[131] Several of the shells are typical forms of the genus *Meretrix* (*Cytherea*), many species of which abound in back-waters and at the mouths of rivers. Hislop has noted the similarity between *Corbula oldhami* and a Brazilian species of the estuarine sub-genus, *Erudona* (*Azara,* or *Potamomya*). There is a complete absence of pelagic shells such as cephalopods, and no echinoderms or corals. The four species *Bullinus prinsepii, Lymnae subulata, Vivipara* (*Paludina*) *normalis* and *Corbicula ingens,* are members of the fauna, and have been quoted as fresh-water forms, but the *Corbicula,* which is common, may perhaps have lived in brackish water, as its near ally, *Cyrena,* does at the present day, while of the other three comparatively rare shells the

[129] S. Hislop, Q. J. G. S., 16, 161, 176 (1860) Mem. 16, 324 (1880): Q. J. G. S., 10, 471 (1854).

[130] W. King, *Mem.* 16, 233 (1880).

[131] The shell described as *Cerithium multiforme* appears to be either a *Tympanotomus* or *Pirenella C. deithi* has the characteristic from and sculpture of a *cerithidea,* and *C. stoddarti* is as much allied to *Potamides* as to *Cerithium.* proper.

Bullinus, according to Annandale, is a variety of probably estuarine habit, for which the name *Euryhalinus* has been proposed.[132] The conclusion is that the Inter-Trappean beds of Rajahmundry were deposited in brackish water, which has been supplied with fresh water by streams bringing down a few fresh-water shells, but was also in communication with the sea, as shown by the presence of minute foraminifera (Miliolidæ, Lagenidæ, Rotalidæ, etc.).

In the marl and limestone from both the Kateru and Pungadi localities, Messrs. S. R. N. Rao and K. S. Rao have recognised the following foraminifera[133] :

Sigmolina, several species,
Triloculina aff. *laevigata* d'Orb.,
Cristellaria (*Robulus*) sp.,
Cristellaria (*Robulus*) cf. *occidentalis* Cushm. & Jarv.,
Nodosaria zippei Reuss (a species found by Chapman to be invariably restricted to the Upper Cretaceous. *Ann S. Afr. Mus*, Vol. 12, p. 117),
Nonionina (*Nonion*) sp., (species apparently identical with a Ranikot form Palaeocene) from the Samana range in Kohat),
Textularia (*Gumbelina*) *globifera*, Reuss,
Orbulina cf. *O. universa* d'Orb. (very common at Pungadi ; *Orbulina* is a typical pelagic genus restricted to Tertiary and later formations),
Spheroidinella sp. (a pelagic form ; frequent at Pungadi),
Globotruncana sp.,
Globorotalia cf. *menardii* d'Orb.,
Anomalina rudio Reuss (A shallow water species).

Recently the discovery by Messrs. L. R. Rao, S. R. N. Rao and K. S. Rao of species of the fresh-water plant *Chara* in these sediments near Kateru, throws important light upon the age of the associated traps.[134] The species, *Chara wrighti* Salt., *C. helicteres* Brongn., *C. cœlata* Reid & Groves, *C. turbinata* R. & G., *C. vasiformis* R. & G., and *C. strobilocarpe* R. & G., are described as well represented and are all distinctive early Tertiary types, especially the first three mentioned. In view of the recognised zonal value of the Charophyta, a group characterised by the easy dispersal of its members, the Lower Tertiary age of the associated traps is considered by some to be strongly supported, in spite of the fact that very little is known of the Cretaceous ancestors of the forms described.[135] Some limestone from the lowest Inter-Trappeans near Pungadi and Dudkur have likewise yielded algal remains, belonging to the Dasycladaceae and including the early Tertiary genus, *Acicularia*,[136] *Neomeris* (*Rec.* 71, 389, notel (1937), and *Holosporella* cf. *siamensis* Pia. *Terquemella lenticularis* Rao, Rao and Pia, ? *Dissocladella* sp., ? *Acetabularia* sp.,

[132] Rec. 51, 57 (1920).

[133] Rec. 71, 389 (1937).

[134] Several species of *C. cypridae* and of *Chara* from the Inter-Trappeans between Nagpur and Hyderabad were described in 1837 by Malcolmson and Sowerby.

[135] Thirteen species of Charophyta from the Inter-Trappeans of Rajahmundry have been described by M/s. K. S. Rao and S. R. N. Rao (Pal. Ind. New Ser. Vol. 29, Mem. 2 (1939)) ; two of them are oligocene species, one of them an abundant species in the Rajahmundry beds.

[136] Proc. Ind. Acad. Sci., Vol. 3, 157-164 (1936).

("*Current Science*", No. 8, Feb. 1938, 376). The last mentioned is of rare occurrence in the Rajahmundry area (Pungadi) and belongs to a species which, curiously enough, has hitherto been found only in the Kamawkala limestone, a formation of the Burma-Siam border assigned to the Upper Trias on palaeontological grounds.[137]

Compared with the Nummulitic fauna of western India, there are no identical forms, if we except the *nonionina*. *Natica stoddardi* is closer to the Cretaceous *N.* (*Mammilla*) *carnitica* than it is to the *Natica dolium* found in the Tertiaries of Sind and Cutch. *Turritella prœlonga* is extremely close to the Cretaceous *T. elicita*, and shows some resemblance to the Tertiary *Turitella affinis*. *Cerithium stoddardi* is more closely matched by the Cretaceous *C. vagans* than by an unnamed *Cerithium* in the Eocene of Sind and Cutch. There may be other species allied to forms in the Cretaceous of southern India which had not been described when the Rajahmundry fauna was examined. The evidence as to the precise age of these Inter-Trappeans of Rajahmundry, therefore, is not conclusive, though there is perhaps a slightly greater incentive to refer them to the earliest Tertiary than to the uppermost Cretaceous. The molluscan fauna shows no Tertiary alliances of any value, and appear to be rather with the Upper Cretaceous of the Coromandel coast. That the beds and the subjacent trap flows cannot be older than Maestrichtian (Danian) is indicated by the fact that the latter lies upon a slightly eroded limestone containing *Cardita beaumonti*.

(b) UPPER INTER-TRAPPEANS.

The Inter-Trappeans so far considered are all believed to belong to the lower part of the Trap series. There remain to be described the much less widespread sedimentaries in the upper traps of the Bombay Presidency. About 2,000 feet of horizontal Deccan Trap beds are exposed on the flanks of Matheran hill, and a still greater thickness further to the east in the hills which include the Bhor Ghat and those which skirt the Great Indian Peninsula Railway line to Poona, but it is impossible to say how far the lowest beds, exposed at the base of the hills, are above the bottom of the Deccan series, since nothing lower than the traps is seen. Owing to the numerous breaks in the section, it is difficult to estimate the precise thickness of the rocks dipping to the westward near Bombay but, taking the average dip to be 5°, the total thickness would be nearly 7,000 feet. This is a minimum estimate, as the average dip may well be higher[138] and the thickness consequently greater. From 1,200 to 1,500 feet of rock are exposed in Bombay Island, including one or possibly two intrusive sills, and the lowest flows seen there should be higher

[137] It seems not at all unlikely that limestone specimens collected from the Kamawkala range come from more than one formation and belong in some cases to the late Cretaceous or early Tertiary.

[138] The dip in Bombay Island is from 10° to 15° (C. S. Fox, Rec. 54, 117 (1922).

in the series than the highest flows seen on the Western Ghats to the east, though some of the loftier portions of the range are 4,000 feet above the sea, always assuming that no considerable fault with a downthrow to the east intervenes between the Island and the Ghats.

The upper Inter-Trappeans, so far as is known, are confined to the Bombay region, no sedimentary rocks having hitherto been found amongst the middle portions of the Deccan Trap series. Manifestly the Bombay fresh-water beds belong to a very different horizon from that to which the Inter-Trappeans of the Central Provinces and the Narbada valley must be assigned. The most important bed is that which underlies the basalt of Malabar hill and Warli hill, forming the broken ridge along the western or sea face of the Island; this stratum is consequently immediately beneath the highest lava flow known to occur anywhere throughout the Trap area, for the rocks, as already stated, dip to the west, and no beds higher than those of Bombay have so far been discovered.

Thickness and Lithological Character.—This Inter-Trappean band on the east side of Malabar hill is more than 100 feet thick in places, and consists principally of grey, greyish blue, brown and brownish yellow, soft earthy shales, with occasional harder bands, some of which are carbonaceous. The greater portion of the bed is evidently formed of volcanic detritus. At the top of the deposit the shale occasionally becomes hard and siliceous, like most beds overlain by the basalt. Locally the carbonaceous shale is highly bituminous and sometimes contains small layers of a coaly substance and fragments of mineral resin. Vegetable impressions abound, though seldom well preserved, and remains of animals are common, the best known being skeletons of small frogs and cyprid carapaces.

Besides this thick sedimentary band, several thinner beds have been found at lower horizons amongst the lava flows and ash beds of Bombay Island. They are, however, very thin and, except one which is seen in the quarries of Nowroji hill south of Mazagaon, difficult to detect; in fact their occurrence has been made known solely through excavations for buildings, tanks and roads. According to Buist there are five or six sedimentary beds below the thick band of Malabar hill, but fossils have only been found in that exposed at Nowroji hill, where cyprids occur. All these bands consist of shaly beds.[139]

Organic remains.—The fossils found at Bombay are comparatively numerous, but hitherto the vertebrates alone appear to have received more than superficial notice. The remains of a fresh-water tortoise, *Rhinemys (Hydraspis) leithi*, belonging to the Emydidae, and of a frog whose form agrees well with the genus *Oxyglossus*,[140] have been found, the latter in abundance; some bones of a larger frog

[139] H. J. Carter, Journ. Bomb. Br. Roy. As. Soc., 4, 161 (1853), Geological papers of western India, p. 128; Buist, Trans. Bomb. Geogr. Soc., 10, 195 (1852). Mem. 5. 193 (1866); Mem. 6, 385 (1869).

[140] *Rana pusilla* of Owen, Q. J. G. S. 3, 224 (1847), but *see* Stoliczka; Mem. 6, 387 (1869).

have also been obtained. The Arthropoda are represented by three species of *Cypris*, one of which, *C. cylindrica*, is also found in the Inter-Trappean deposits of the Deccan; another species has been called by Carter *C. semimarginata*, while the third is unnamed. *C. semimarginata* is the most generally diffused, but the other forms also occur in great numbers. Only fragments of insects have been found, and some fossil mites—*Gamasus fossilis* Mani—have been recognised. Of the rare Mollusca, the few specimens hitherto procured are poorly preserved and have been referred with some doubt to *Melania* and *Pupa*; none of the characteristic Deccan forms has been detected. Plant remains comprise stems, leaves, seeds and perhaps roots, but little is known of them beyond the fact that Monocotyledons and Dicotyledons are represented.

The life illustrated by the species named is clearly that of a shallow marsh. The frogs occur in large numbers, and their bodies have evidently been deposited near the spot where they died, as the whole skeleton is found perfect; in some cases, the skeleton shows signs of having been dragged along the surface of the shale in which it is embedded. The tortoise is a marsh or river form, the nearest living ally. according to Gray[141], being a genus found in fresh water in South America, to which region the genus *Rhinemys* (Hydraspis) is now confined.

Ahmedabad Boring.—In a boring for water put down recently in Ahmedabad two Inter-Trappean beds were encountered among the traps made up of grits and sandstones containing some pebbles of trap; one was 42 feet thick, and of the other 102 feet had been pierced when the boring was abandoned at a depth of 1951 feet.[142] These Inter-Trappean beds are of great interest since they belong neither to the known Lower nor to the Upper horizons, and indicate that sedimentary intercalations are not entirely absent from the intermediate traps.

Trap intrusions.—Having discussed the sedimentary intercalations, we now turn to the intrusions found in the Deccan Trap. These consist both of sills and dykes though the two types sometimes merge into each other and it is not always possible to say to which category the intrusions belong. It is of course not easy always to distinguish intrusions of whatever shape amongst effusive rocks of precisely similar mineral character, and it is only where dykes are large and numerous that attention is likely to be directed to them. Much work still remains to be done before the distribution of dykes, sills and ash beds is fully elucidated. So far as investigations have proceeded, intrusions are more prevalent in the west coast region, from Mahabaleshwar to the neighbourhood of Baroda, than in other parts of the Trap area, with the exception of north Chhindwara and the adjoining portions of Hoshangabad and Narsinghpur, all of which have been the subject of a recent survey. Further work may prove that the existence of such nests of dykes

[141] Ann. Mag. Nat. Hist., 4th Ser., 8, 339 (1871).
[142] Gen. Rep. Rec. 60, 56 (1927).

is more widespread than was originally thought. While the smaller dykes are probably merely fissures filled with molten material, the larger dykes in many cases were the means of egress for the flows. Assuming that the molten basalt flowed for distances not likely to exceed 50 or 60 miles, we must presuppose an extensive system of such feeders beneath the great tract of lavas which now conceals them.

One tract of country in which dykes are peculiarly large and abundant is situated in the Rajpipla hills, northwest of Surat. Over a considerable area, very large parallel or nearly parallel, basalt dykes are found sometimes not more than two or three hundred yards apart, the general direction being east-by-north to west-by-southwest. Here the traps are much disturbed and frequently dip at considerable angles.

South of the Tapti, along the crest of the Western Ghats, and its neighbourhood in western Khandesh, the northern Konkan and the intervening small States, it will probably be found that dykes continue to be numerous for a considerable distance, since their number and size in the Konkan northeast of Bombay have been specially noted by G. T. Clark.[143] Intrusions are far from abundant in the lava flows exposed in the higher country east of the Ghats; at the same time the frequent occurrence of ash beds in the higher traps around Poona and Mahabaleshwar attest the proximity of old volcanic vents. In the Malabar ridge and Worli hills of Bombay Island, Fox has shown that an intrusive sill of dolerite has made its way along the undersurface of an effusion of trachyte. This sill, as Carter had concluded much earlier, followed the course of the Inter-Trappean Frog beds which had formed the floor of the trachytic effusion. In doing so it fractured the sedimentaries and included fragments thereof, some of them as large as a man's fist. It also seems to have caught up from these fresh-water strata some of the bituminous matter which the shales are known still to contain. This material is now found in the form of black asphalt lying on the floor of cavities in the sill; the sides and roof of these cavities as well as the surface of the asphalt they contain are encrusted with crystals of calcite, quartz and zeolites of various kinds. The asphalt, in places associated with wax and liquid petroleum, is partly soluble in carbon disulphide, burns readily with a smoky flame, and contains over 88 per cent. of carbon.[144] As we have seen, this area of intrusion is one also of tectonic disturbance.

North of the Rajpipla hills and of the river Narbada, and to the west of Baroda, trap dykes are not so common as they are in the Rajpipla hills themselves, but intrusive masses do occur. One of these, forming Matapenai (Metapenai) or Karali hill, 14 miles southwest of Chhota Udaipur, is a mass of grey trachyte or trachy-dolerite, containing enormous inclusions of granite, evidently derived from the metamorphic rocks through which the mass, when molten,

[143] Q. J. G. S., 25, 164 (1869).
[144] C. S. Fox, Rec. 54, 121 (1922).

passed on its way to the surface. Three other trachytic cores, intruded through the basalts, are recorded near the village of Padwani, 18 miles east of Broach.[145] The occurrence in intrusive trap dykes of fragments derived from the metamorphic rocks is by no means uncommon.

It is only natural that better evidence of intrusion should be found outside the Trap area, or in the inliers of older sedimentary rocks, than amongst the lava flows themselves, and the distribution of such intrusive masses, so far as is known, is as follows. Commencing from the northwest, no trap dykes have been found in Sind where, however, deposits of older date than Eocene cover an exceedingly small area. In Cutch intrusive masses of basalt and dykes of large size abound throughout the Jurassic rocks, some of them rising to hills of considerable size ; one of the latter, Denodhar, by name, may be the basaltic core of a volcanic vent. Intrusions are abundant throughout Kathiawar, especially in the central and southeastern portions of the Trap area and in the Umia outcrops beyond. Here the dykes are very numerous and large, often forming prominent features in the landscape. The prevalent direction is E.-W., with a set of later cross-dykes more or less at right angles, but there are exceptions to this arrangement, especially in the Umia outcrops. Occasionally the dyke rock is amygdular, especially where it joins that of a flow. The width of the dykes in Kathiawar ranges up to about 200 feet ; the large Sardhar dyke, nearly 100 feet across, has been traced for about 45 miles. Some of the dykes are very irregular and without definite walls ; near Than they form a tangled network of intrusions, while some of the Kathiawar dykes can be seen to have penetrated 300 or 400 feet of the Umia sandstones, but stop short.[146] In places the edges of the sandstones have been upturned by the intrusion. The sandstones of this region are described as having been indurated by the dykes, the hardened portion resisting denudation and weathering to narrow craggy ridges along the sides of the intrusion.

Throughout the northern edge of the Trap country in Rajputana, Gwalior and Bundelkhand, dykes are rare or wanting, but they abound in some of the areas of older rocks exposed in the Narbada valley ; here intrusive sheets can be seen following the bedding planes of the Bagh beds between Gora and Sulpan and at several places in the Deva valley.[147] Dykes of Deccan Trap age abound in Rajpipla State where the direction is usually E.-W. Flows can be seen to have issued from dykes in Betul, and some of the latter occupy faults[148].

Dykes are especially common in the Gondwana tract, south of the Narbada in the neighbourhood of the Mahadeo (Mahadeva)

[145] Rec. 37. 173 (1908).

[146] F. Fedden. Mem. 21, 103 (1933).

[147] Rec. 37. 173 (1908).

[148] Rec. 55, 36 (1923).

hills. Connected with the latter area we have the most recent and detailed account yet published of the Deccan Trap intrusions.

Over the northern slopes of the Mahadeo hills Crookshank finds that trap intrusions are rare in the crystalline rocks, comparatively common and of both types among the trap flows, and very abundant in the Gondwana areas. The distribution of the intrusives is intimately connected with the nature of the rock intruded. Most of the sills, for instance, occur in the shaly Bijoris, or at the top of the Denwas near their junction with the overlying Jabalpur sandstones; in both cases the intruded rocks are soft and fissile and the overlying rocks massive resistant sandstones. Sills, in fact, seem to have been formed only where the superjacent rocks were tough enough to prevent dykes forcing their way through them. The dykes, like the sills, have selected the softest strata, or have taken the path of pre-existing faults. Both intrusive types have been driven upwards by the same forces, and can be seen passing the one into the other. As a rule, the sills are not uniform sheets but have highly irregular upper and lower surfaces, and pass in a haphazard manner from one level to another; their thickness varies rapidly from place to place, a normal figure being between 200 and 400 feet. Some of the sills are multiple and split into two or more separate horizontal sheets. The sills were fed by the main dykes with which they are united. According to both Medlicott and Crookshank a sill may pass laterally into a flow, emerging perhaps from between sedimentary strata into the open; in doing so the texture changes from doleritic to a much finer rock and frequently becomes amygdular.

The dykes of the Mahadeo area vary in size from thin tachylitic veins to enormous intrusions 100 yards or more in width and extending for many miles usually in an E.N.E.—W.S.W. direction, *i.e.*, parallel to the drain of the country. In many cases they are not continuous but form elongated lenticles in the fault planes. Many of the larger dykes bifurcate and some give off ramifying apophyses; a few are multiple, the central newer portion being finer in grain than the outer marginal portions, and in some cases more acid. The most massive, though not the longest, dyke does not coincide with a fault plane but zig-zags right across the strike of the Gondwana rocks from one side of the Mahadeo range to the other; on both sides of the range it appears to be connected with a large sill-like intrusion. E. A. Jones also records in this region the union of four sheets of trap, varying from 2 to 30 feet across, into a wide dyke; these sheets, which are separated from each other by layers of sandstone and follow the dip of these beds, are irregularly connected with one another and form part of a roughly reticulated system.[149] In the Pench Valley coalfield of Chhindwara a dolerite dyke, ranging up to 4 feet across and now largely decomposed to a white clay, has coked the coal on either side for about 18 inches.[150]

[149] Mem. 24, 51 (1887).

[150] C. S. Fox, Rec. 44, 123 (1914).

Continuing our survey of the Deccan Trap intrusions, we find them less numerous in east of the Mahadeo hills, but present in Seoni,[151] Mandla and throughout the upper Son valley; in Mandla there is a good example of a multiple dyke formed by the union of six individual dykes.[152]

A large and important sill has been described by Sir Lewis Fermor in Korea State, and has been fed by some of the dolerite dykes which form part of a dyke system, veering from E.-W. to N.E.—S.W., mostly confined to the Talchir outcrops but seen also in the Barakars;[153] the main feeding dyke stretches, in fact, interruptedly for 26 miles, and probably extends beyond into Archaean rocks. A large, irregular, remnant of this sill is seen immediately north of the Kurasia coalfield; here it is a coarsely crystalline dolerite in the centre, becoming finer textured away from the centre and basaltic along its marginal portions. It has been traced for some 38 miles, stretching E.N.E. into Sarguja and probably responsible for many of the trap outliers in the Sohagpur coalfield of Rewah to the west. In one place 400 feet of this sill have survived weathering, but since the uppermost layers here consist of the most coarsely crystalline type of the dolerite and therefore probably represent the middle of the sill, we may deduce that 300 or 400 feet have been removed by erosion and that the original total thickness must have been 700 or 800 feet at this point. With a general N.N.W. dip of about 22°, this interesting sill has invaded the topmost layers of the Talchir rocks its more easterly portion rising into Barakar horizons.

The Deccan Trap intrusions die out in Sarguja and Palamau, some 200 miles west of the older flows of the Rajmahal hills. Nevertheless, within a 100 miles or so are the Gondwana basins of the upper Damodar valley, traversed by basalt and dolerite dykes which at one time were thought to be of the same age as the Rajmahal traps, but which there is now reason to regard as largely, if not entirely of Deccan Trap age. Passing southwards from Jubbulpore and Mandla, there is a total absence of volcanic intrusions amongst the Vindhyan and Gondwana formations of Nagpur and Chanda, and none has yet been noticed in the neighbourhood of the Pranhita and Godavari between Chanda and Rajahmundry. The country south of the Godavari and northwest of Hyderabad is still imperfectly known, but in the south Maratha country, and in the Konkan near Vengurla, the few dykes which have been observed traversing the unmetamorphosed Purana strata are but doubtfully connected with the Deccan Traps; ashes, incidentally, are also much less abundant in this region, amongst the Deccan flows, than they are further north. The large dykes traversing the ancient crystalline rocks of Coorg in a direction approximately W.S.W.—E.N.E. probably belong to the series under consideration; they are formed of a very fresh basic

[151] Gen. Rep. Rec. 44, 36 (1914).

[152] Gen. Rep. Rec. 45, 134 (1915).

[153] Mem. 41, 156 (1914).

rock composed of augite and felspar in the south, but containing olivine in addition in the north.[154]

The usual rock of the sills is a dolerite of varying coarseness, in the largest masses approaching a gabbro. In most cases it is markedly ophitic. Some of the sills are locally porphyritic, with rounded and lath-shapped phenocrysts of felspar and less commonly augite, up to an inch or more in length. The sills are finer in grain along their margins, may be coarsely columnar, and often weather spheroidally. Their petrographic characters show no essential difference from those of the flows, the chief contrast being the absence or rarity of vesicles and amygdules and perhaps a somewhat larger proportion of olivine and apatite in the intrusive rock. Crookshank records a definite tendency in the sills for olivine crystals to accumulate towards the base.

The dykes also show all degrees of texture from a coarse dolerite to a fine-grained basalt; they are often granular, sometimes porphyritic, but much less frequently ophitic than are the sills. Like the sills they are mostly non-vesicular, the coarser varieties usually weathering to spheroidal boulders, the finer ones showing a columnar tedency. Tachylitic selvedges are common in the basalt dykes, but not in the doleritic varieties. Petrologically the larger dykes rese ble the sills, and the smaller ones the flows.

Although the intrusive sills and larger dykes are in the vast majority of cases doleritic, the converse is not true. as Fermor and Fox have shown in their work on the Linga area, where several unquestionable flows are composed of dolerite.

Where an intrusion cuts across a flow, chilling effects are almost entirely confined to the intrusive rock. The main features in the chilled zones of the sills are described by Crookshank as a rapid increase of glass in the rock towards the margin, the disappearance of iron ores as the glass increases, and the presence of iddingsite.[155] Where Gondwana sandstones have been invaded, the junction is occasionally marked by a fused sandstone in the form of a black, cellular chert. Carbonaceous shales, thus intruded, are always bleached and often baked to a creamy porcellanite in which fossils are sometimes perfectly preserved; coloured clays also show bleaching. An interesting contact phenomenon is mentioned by Crookshank from the vicinity of Bijori where the tachylitic upper surface of a dolerite intrusion has received the impress of ripple-marking from the Bijori Shales above. Dykes of sandstone, often seen in the dolerite near its margin and varying from two or three inches to the same number of feet, may extend for hundred yards or more, and appear to have been spilt off from the main mass of the sedimentary rock, more or less engulfed in the molten magma and sometimes distorted by the movement of the latter. These are the vertical equivalents of the false Inter-Trappean sandstones separated off by the sills and mentioned on page (1376).

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[154] Gen. Rep. Rec. 30, 31 (1897).
[155] Mem. 66, 325 (1936).

The effect of heat upon an invaded sedimentary rock may be confined to a few inches from the surface of contact, but the zone affected by aqueous emanations from the intrusive is often large. That some at least of the silica deposited by these emanations dates from a time when the latter were still hot seems indicated by the presence of numerous cavities containing zeolites in the chert which permeates some of the Gondwana clays.

Origin and mode of formation of the Traps.—The hypothesis of a sub-aqueous origin in the case of the Deccan Traps is untenable for several reasons. In the first place, the volcanic ashes, already described as occurring in great abundance amongst the higher beds of the Deccan Traps, are not, as a rule, stratified in the manner in which beds deposited from water would be. Although they occur in strata intercalated with the basaltic lava flows these ash beds themselves have no internal lamination, except in a few rare instances in which they are chiefly composed of bole and may have been formed in the small pools of fresh water so common in volcanic areas. Above all, no trace of a marine organism has ever been found in any of the ash beds, or in any rock intercalated or associated with the traps, except in the Infra-Trappean and Inter-Trappean deposits of Rajahmundry, where the lava was evidently poured out on the coast.

The relations of the lowest lava flows to the underlying rocks are strongly antagonistic to the idea that the volcanic outbursts were sub-aqueous. The surface of the older rocks upon which the traps rest is in many places extremely uneven, the basalt filling valleys, some of them as much as 1,000 feet in depth, whose form shows that they were excavated by subaerial erosion. Where the underlying formation consists of the Cretaceous Bagh Beds, these, although showing no visible unconformity to the volcanic series over a large part of the area, are seen in certain places to have been locally disturbed to a small extent, and to have suffered erosion previous to the volcanic outbursts. Here and there the sedimentaries are wanting, the level of the Infra-Trappean surface showing that their absence is due to denudation. In some cases where the Bagh beds are not more than 30 or 40 feet thick, the denudation which removed them extended over a very small area, often only a few yards wide, and the denuding agent must obviously have been subaerial erosion. Finally, with the single exception of the estuarine Inter-Trappean band of Rajahmundry, a relic probably from the very fringe of the original expanse of the lava tract, every fossiliferous sedimentary bed intercalated with the Deccan Traps is unmistakably of freshwater origin; in this we have positive evidence that the traps were not of submarine but of subaerial origin. Furthermore, the thinness and intermittent occurrence of the Lametas and Inter-Trappeans as well as the character of the faunas found therein, point to a large number of shallow lakes, pools or marshes of moderate or small size, scattered over the surface of the country.

Many such masses of horizontal stratified traps are found in various parts of the world, and are not confined to any particular

epoch, although several instances are known of outbursts of about the same geological age as that attributed to the Deccan Traps. Such effusions are well developed in the western parts of North America where single flows of basalt can be followed for 50 or 60 miles. In this region the total thickness is about 2,000 feet, rising in places to 3,700 feet, the lavas following the sinuosities of the mountain base which bounds them to the north and east; a few small cinder cones have been noted along the margin and elsewhere and appear to have been formed during the closing stages of the disturbance. Another large basalt tract covers the greater part of Abyssinia. An immense area of basalt flows covers northeast Ireland, the Inner Hebrides, north England and parts of Scotland, including the Orkneys and Shetlands and probably extended continuously through the Faroe Islands to Iceland and Arctic Greenland. It is, in fact, to Iceland we must go to find the equivalents of the Deccan and other similar eruptions within historic times, and a few facts regarding these modern displays of subterranean energy on a large scale will assist comprehension of the conditions which prevailed during the age of the Indian Deccan Trap.

According to Sir Archibald Geikie, large tracts of Iceland have been rent by fissures which belong to two principal systems forming an angle of 45° with each other. Some of the fissures have been traced for nearly 50 miles. When quiescent a fissure may remain as an open chasm 600 feet or more in depth; when active, lava rises in it and flows out tranquilly on either side, sometimes forming a line of slag-cones along the line of the chasm or a long rampart of slags and blocks piled up on either side. "The great eruption of 1783 issued from the Laki fissure, about 20 miles long, and poured forth in two vast floods, of which the western branch flowed for upwards of 40 miles and the other 28 miles.[156] Hundreds of slag cones of insignificant size were formed along the line of this fissure. The Icelandic lava is described as remarkably liquid, flowing to a great distance where the ground is inclined and filling up valleys with a succession of more or less horizontal sheets, which are eventually dissected into ravines by rivers. In some parts of the island the lava has built up vast flat domes like those of Hawaii, having a gentle inclination in every direction. The Vesuvian type of cone, made up of alternating lavas and tuffs, is also to be found in Iceland, and the presence of explosive craters shows that eruptions are not always of a gentle nature. Great though the emission of pumiceous stones and dust from the latter must have been, very little trace has been left round the inconspicuous orifices. One of the prehistoric lavas in Iceland flowed for a distance of more than 60 miles. Throughout this basaltic tract of northwestern Europe, extravasation of more acid material is very local in its manifestation. Occasionally thin sheets of rhyolite and trachyte are to be seen in the basalt terraces of Mull, Skye and Antrim. The basalt has also been invaded by large bosses of gabbro and various granitoid rocks, and more especially by enormous numbers of basalt dykes.

[156] Sir A. Geikie, Test-book of Geology, p. 342 (1903).

A comparison of the features of the Recent Icelandic with those of the Deccan lavas shows how closely parallel they are. To recapitulate, the Deccan Traps belong to that category of eruptive rocks known as Plateau Basalts, the extrusion of which has taken place from innumerable fissures over an enormous area. All evidence in India supports the conclusion that in nearly all cases the floods of lava welled quietly from these vents or perhaps issued from numerous small vents along the course of these fissures, and flowed for distances of perhaps 50 or 60 miles. The magma, as did that of South Africa, when it failed to force its way up through overlying beds of basalt, found its way laterally as sills along the bedding planes, and in some cases emerged into the open as flows. In this way a vast tract of country was flooded with lava without the building up of any conspicuous cone to which the term volcano would be typically applicable, for with one or two exceptions which will be described later, no traces of such cones have been recognised. Although lava flows predominate over fragmental discharges, as they do in the analogous volcanic manifestations in other parts of the globe, the latter are abundant among the higher traps and bear witness to a more violent form of eruption. Where the ash beds include, as they usually do, a coarse volcanic breccia, containing blocks several inches in diameter, it is evident that they could not have accumulated very far from the points of ejection, though they may have been floated for some distance on the surface of molten lava. For the location of the points or planes of emission we have the evidence of the dykes, any concentrated assemblage of which we may assume to mark proximity to some line or lines of extrusion. Of such assemblages we find evidence in Cutch, the Rajpipla hills, the lower Narbada valley, the northern slopes of the Mahadeo hills, the neighbourhood of the Western Ghats, east and northeast of Bombay, south Rewa and Sarguja. On the other hand the Nagpur and Chanda districts and the country southeast thereof are generally devoid of Deccan Trap dykes ; whether the south Maratha country and southern Konkan are also, is not certain.

The general E.-W. or W.N.W.—E.S.E. direction of so many of the intrusions supports the suggestion that the outbursts of Deccan Trap were a continuation of the disturbance which produced the Gondwana faulting. In some cases, the grain of the country rock invaded played a prominent role and may have been the main factor in determining the orientation of the fissures. The general normality of the faults is proof that this part of the earth's crust was in a state of tension immediately antecedent to the compression of the Himalayan movement which acted along much the same direction.

The individual sheets of the Deccan and other Plateau lavas, though actually often of considerable thickness, are extremely thin when compared with their horizontal dimensions. The general horizontality and enormous extent of these lava flows are proof of a low solidifying point and extreme liquidity. These two traits are especially characteristic of basalt, and it is precisely this mode of

extrusion which is effected by this rock. Nevertheless basalt is sometimes ejected from volcanoes of the explosive type, is found consoli dated on steep slopes, and flows to no great distance from the vent. There are thus two different kinds of basalt, and the broad general distinction between the two, according to H. S. Washington[157], is the presence in the Plateau variety of a much higher amount of iron oxides, with ferrous oxide greatly predominating over ferric oxide, and an appreciably higher percentage of titanium dioxide ; the cone basalts, on the other hand are relatively high in magnesia and lime. Mineralogically this chemical difference is expressed in the presence of highly ferromagnesian, hedenbergitic enstatite-augite in the Plateau basalts, in contrast to that of highly calcic diopsidic augite in the cone basalts. The fluidity and low solidifying point of the Plateau basalts is due mainly to their high percentage of ferrous oxide.

Some experiments by Crookshank give us an approximate idea of the temperature of some of the Deccan intrusions. If this temperature had been higher than the melting point of the clays intruded, the latter could not have escaped fusion, as they have. As shown by the collapse of seger cones, these clays were found in the laboratory to commence to fuse in the air at about 1,000° C. From this it is concluded that the temperature of the magma was probably less than 1,000° when first intruded ; that it remained liquid to a much lower temperature than this is suggested by the presence of quartz and the absence of any trace of its high temperature form tridymite[158]. Such a conclusion loses none of its interest from the possibility of its being of purely local significance, for the concentration of felsper phenocrysts in the lowest layers of some of the flows or sills may indicate, as we have seen, a sinking of these crystals in a magma having a temperature exceeding 1,100° C.

Unusual Types.—A brief reference is now necessary to some of the unusual types of igneous rock which locally accompany the basalts and dolerites. The most important of these are found in the Junagarh State of Kathiawar and are exposed chiefly in the two hill masses of Junagarh and Osham. Fedden was of opinion that they were grouped round one or more volcanic vents of the normal "cone" or "central eruption" type,[159] but the occurrences have since been shown to be laccoliths intrusive into the basalts from below.

The great central mass of the Junagarh hills, called the Girnar, is over 3,500 feet in height and belongs probably to a late phase of the Deccan Trap activity. The outer annular ridges, steeply scarped on the inner side but sloping outwardly at varying inclinations, have been more readily eroded. The mountain originally must have possessed vast proportions compared with its present denuded remnant. The rocks included acid and intermediate types as well as basic. Among the basic rocks, according to M. S. Krishnan,[160]

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[157] Bull. Geol. Soc. Amer., 33, p. 800 (1922).
[158] H. Crookshank, Mem. 66, 326-7 (1936).
[159] Mem. 21, pt. 2 (1884).
[160] Rec. 58, 382 (1925).

hypabyssal and volcanic types greatly predominate, comprising basalt, dolerite and olivine dolerite of the usual kind, lamprophyre and monchiquite and the ultrabasic limburgite; basic plutonic rocks have been identified as diorite-gabbro and olivine-gabbro. The intermediate rocks are mostly plutonic, the predominant type being a nepheline-syenite; in addition are alkali-syenite, and the finer textured syenite-porphyry, syeno-diorite, porphyrite, andesite and augite-granophyre. A quartz-porphyry or granophyre represents the acid group.

The central mountain is a broad dome of diorite and monzonite. This is surrounded by a ring-shaped outcrop consisting mostly of olivine-gabbro but partly of basalt. Beyond this is the basalt of the Deccan Trap out of which crops another broad broken concentric ring of granophyre. The intruded basalt has a quaquaversal dip and has been arched by the laccolith, one result being the formation in the former rock of a concentric system of fractures which have given access to the large curved dykes of granophyre. In the marginal portions of the latter can be seen abundant sharply angular xenoliths of the basalt. Neither these fragments nor the main mass of basalt show any signs of contact metamorphism. In one place Mathur, Dubey, and Sharma found large blocks of conglomerate sandwitched between the granophyre and basalt, evidently brought up from below by the granophyric magma.[161] The extreme compactness of the granophyre and its consequent resistance to weathering made it a suitable basis for the celebrated inscription of Asoka which is well preserved after an exposure of over two thousand years.

According to J. Evans, the sequence of events in the Junagarh hills was follows.

Following the extrusion of the dolerites and basalts, which now occupy the more outlying parts of the hills, was large laccolithic intrusion of olivine-gabbro which can be seen passing up into diorite and monzonite. Next came an intrusion of alkali-rich syenites. Finally, small masses of limburgite and lamprophyre were squeezed into the earlier rocks of the central mass. That the succession of events was comparatively rapid seems to be indicated by mixture between the different types. It is of interest to compare this succession with the sequence of intrusions shown by Miss. H. K. Cargill, L. Hawke and Miss. J. A. Ledaboer to have taken place in southeastern Iceland[162], where the Tertiary basalts have been invaded first by stocks of gabbro and afterwards by granophyre and granite.

The country between the Junagarh hills and Osham hill is made up largely of igneous rocks, often traversed by dykes, mostly of basalt and dolerite but occasionally of microgranite. The widely divergent products of differentiation in the isolated Osham hill comprise basic rocks in the south and west and acid lavas in the north-east. The amygdaloidal basalt which forms the base of the hills is

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[161] Journ. Geology, Vol. 34, 289-307 (1926).
[162] Q. J. G. S., 84, 505-535 (1928).

covered by a few feet of pitchstone, the remaining three-quarters of the hill consisting almost entirely of rhyolite, some of which shows flow-structure. A specimen of spherulitic obsidian comes from this hill, and some agglomeratic beds are recorded.

A little to the northwest of Osham, a group of hills to the west and northwest of Dhank consist of more or less acid types, (the "felsites" of Fedden), some compact, tough and silicons, others trachytic. A few miles west of these hills is another group known as the Barda hills which are made up of rocks very similar to those in the western ridge of the Junagarh mass. Similar acid rocks, some porphyritic, others agglomeratic, are recorded at Sihor, 12 miles west of Bhawanagar[163], and at Rajula near Jafarbad ; a band of obsidian is to be seen opposite Sihor, and a band of pitchstone near Rajula. An outcrop of pitchstone is also found in the Bhadar stream below Ranpur ; it becomes trachytic in its lower part, is overlain by a "spheroidal felsite" and underlain by a dull red, compact rock of similar nature[164].

The Chamardi hills, about 16 miles W.N.W. of Bhawanagar, are thought to occupy another centre of intrusion. Rising abruptly from the alluvium, they are composed mainly of rocks similar to those found in the Barda hills and in part of the Girnar. Acid igneous rocks are also found in the neighbouring Chogat hills.

Among the 48 flows encountered by some borings sunk in Ahmedabad and Kathiawar were certain more basic types which have been classified by West as follows :—

(1) Flows with phenocrysts of fresh olivine and augite.
 (a) with groundmass felsper (Oceanites and Ankaramites).
 (b) with no felsper (Limburgites).
(2) Flows with phenocrysts of fresh olivine, augite and bytownite.

Between these and the more normal type with phenocrysts of labradorite and occasionally altered olivine, there are intermediate links. None of the beds is intrusive. That the differences in composition are not due to differentiation caused by the settling of early formed crystals, more especially of olivine, is proved by the fact that the composition of the phenocrysts varies with that of the rock in which they occur. In the ultrabasic varieties, for instance, the olivines are highly magnesian, *i.e.*, rich in forsterite and poor in fayalite, while in the normal type, both in Kathiawar and other parts of India, the olivines are much more ferruginous. The pyroxene of the ultrabasic rocks is one of high optic axial angle, and is quite distinct from the enstatite-augite ("pigeonite") within the composition limits of which the pyroxene of normal plateau basalts falls. Finally the

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[163] The rocks of Bhawanagar have been described by K. P. Sinor ; "Petrographic Descriptions of the igneous and sedimentary rocks of the Bhawanagar territory", Bombay, The Times Press, 1927.
[164] F. Fedden, Mem. 21, 98 (1884).

felspar of group (2) corresponds to bytownite and anorthite in composition instead of to the labradorite exclusively found in the ordinary basalt. This variation in composition of the phenocrysts is reflected in the chemical analyses of the rock as a whole, as shown by the high magnesia content (18·18 to 20·05 per cent.), high alumina (16·88 per cent.), low silica (47·9 per cent.) and low total iron, in which the ferric and ferrous oxides are not very different in amount (4·8 and 5·97 per cent. respectively). The conclusion drawn is that these ultrabasic rocks must have crystallised from melts of their own composition.[165]

A little over 200 miles E. N. E. of the Girnar peak, and 23 miles in the same direction from the city of Baroda, there is an outlier of the Deccan Trap in the Panch Mahals known as Pawagarh or Pavagad, geographically intermediate between the lavas of Kathiawar and those of Khandesh. Pawagarh, a fortress from early times and once the capital of Gujerat, is a huge terraced block of horizontally bedded lavas, some 7 miles in length from north to south, by 4 miles in width, rising like an island to a height of 2,400 feet above the low-lying plain which extends for miles from its base in every direction.[166] The conspicuous character of the hill is largely due to the great height of the vertical and unbroken scarps which bound the various lava flows and impart to the hill its terraced appearance. In it are exposed over 2,000 feet of basalt flows resting upon a platform of Nimar Sandstone which in turn lies unconformably upon the eroded edges of the ancient Aravalli (Champaner) phyllites.[167] The basalts, some of them amygdaloidal, are capped by a single flow of rhyolite which is considerably thicker than any of the basic flows. Between its base and the uppermost basalt are a few feet of soft, earthy, red rock, which is either a tuff or a layer of Murram or decomposed basalt representing an old land surface.

The rhyolite is split into rude vertical monoliths by a system of vertical joints which start from both upper and lower surfaces but mostly end before they reach the middle portion of the rock. The greater resistance of the rhyolite to weathering has played a prominent part in the preservation of this outlier. The rhyolite has been described petrologically by Fermor;[168] phenocrysts of felspar unaccompanied or not by quartz are present in some samples, and fluxion structure is common. This rock is similar in every way to the rhyolites of Osham hill, and both show a marked resemblance to the much more ancient Malani rhyolites of Rajputana; although the peculiar "quartzmosaic" structure is seen in all of them, there are slight mineralogical differences between the older and the newer lavas, the Malani rock being somewhat more acid. The consanguinity of these acid rocks with the basalts is shown by the identical appearance of their augite when present, the comparatively abundant magnetite,

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[165] Gen. Rep. Rec. 66, 20-21 (1932).
[166] L. L. Fermor, Rec. 34, 149 (1906).
[167] Gen. Rep. Rec. 68, 18 (1934).
[168] Rec. 34, 154 (1906).

and the basicity of the plagioclase felspar in some forms of the rhyolite. Among the specimens from Pawagarh is a pitchstone with dacitic affinities, some silicified rhyolttic breccia and rhyolitc ash.

Dykes of trachyte occur in the lower Narbada valley as well as dykes and inextensive sheets of felsite, some of the latter being interbedded with normal beds of trap.[169]

Another differentiate of the original basaltic magma has been found in Salsette Island, and also in the northeast of the Island of Bombay where it is known as the Kurla Trap. This is a granophyric trachyte, which has provided the stone for the "Gateway of India" in Bombay. This rock contains grains of pyrites and calcite, ingredients which detract from its value as a building stone.[170] An acid intermediate rock, possibly related to the nepheline-syenites of Girnar hill, and containing a high percentage of silica and alumina and a low proportion of alkalies, overlies the Inter-Trappean bed of Malabar hill, the Cumballa ridge, and high ground of Worli, in the west of Bombay Island. It is very likely the overlying rock of Golangi hill and, though microcrystalline in its lower part, becomes more coarsely crystalline higher up[171]. Felsites, granophyres, rhyolites and rhyolitic ashes or tuffs are also recorded from Salsette Island.[172]

Three small outcrops of trachytic rocks have been mapped by P. N. Bose east of Jhagadia in Rajpipla State, south of the Narbada. These are surrounded by Tertiary sediments and appear to have intruded through the basic traps which are exposed two or three miles to the east. The largest of these occupies a hill called Karia and is about 2½ miles long and 1½ miles broad.[173]

Some acid dykes are recorded on the northern slopes of the Mahadeo hills, and are no doubt to be found in other parts of the Trap margin. These and other occurrences of less usual intrusive types of Deccan Trap age are of insufficient importance to merit individual enumeration or description.

AGE OF THE DECCAN TRAP SUITE, AND EVIDENCE THEREUPON FROM OUTLYING OCCURRENCES.

General evidence.—With regard to the age of the Deccan Trap series, further investigation may eventually prove that the Rajmahal Trap, as already suggested, represents but the initial phase of the Deccan disturbance. Between the Rajmahal hills and the Deccan Trap margin, as we have seen, dykes of dolerite petrologically identical with sills and dykes of the Deccan Trap are frequent in the Karanpura, Jharia, Raniganj and other coalfields. As Dr. Fox has pertinently remarked, had the earliest observers worked from west to east instead of *vice versa*, a Deccan Trap age would have been

[169] P. N. Bose, Mem. 21, 57 (1884).
[170] Rec. 62, 371-376 (1929).
[171] C. S. Fox, Rec. 54, 124 (1922).
[172] A. S. Kalapesi and G. B. Contractor, Q. S. Geol. Min. & Met. Soc. Ind., Vol. 7, 183 (1935).
[173] P. N. Bose, Rec. 37, 173 (1908).

put forward for all these intrusions in the coalfields.[174] The fact that the rocks of the two denominations are lithologically indistinguishable from each other has always been a subject of remark, and authorities have refrained from classifying them as one only by reason of the wide difference between the supposed Jurassic age of the Rajmahals and the late Cretaceous age of the Deccan Trap. Recent researches, however, tended to have lessened that supposed gap. On the evidence of ammonites, the Raghavapuram and other plant beds on the east coast belong to the lower Cretaceous (Upper Neocomian). These plant beds have always been regarded as not very much younger, if at all, than the Rajmahal series, with which they have many species in common. The Rajmahals, therefore, would seem to demand a position either at the base of the Cretaceous, or at the top of the Jurassic. The Jabalpur series, which is accepted as younger than the Rajmahal, would in that case be given a place above the lower Cretaceous boundary were it not for the conclusions of palæobotanists concerning the Jabalpur flora.

In the Jubbulpore district, Matley finds that there is an almost continuous sequence from the Jabalpur group through the Lametas to the lowest Deccan Trap. As already explained, the age of the Upper Gondwana sequence is a question which needs re-investigation, but it seems highly probable that the succession from the Jabalpur sediments to the overlying Deccan lava bed is not so continuous as it appears to be, and that we have here another example of "condensation" due to long intervals of non-deposition. In spite of its basal position, the bed of lava referred to, is by no means necessarily the oldest trap bed even in its own particular locality, as has already been pointed out. Although we have no definite proof that the Deccan Trap disturbances commenced as early as Lower Cretaceous times, we have no proof that they did not, even if we reject the correlation of the Rajmahal Trap with the earliest phase of the Deccan eruptions.

Furthermore, there are good reasons for assuming that the Deccan Trap disturbances stride a considerable interval in the stratigraphic succession. In support of this idea have been adduced the presence of lacustrine deposits abounding in animal and vegetable remains, of the lateritic layers of red bole, and of Inter-Trappean accumulations of rounded pebbles not only of metamorphic and sedimentary rocks but of the trap itself. Deductions from such facts, however, seem to have somewhat exaggerated. The formation of pools and lakes and their population by animals and plants, the accumulation of lateritic soils, the disintegration of the trap into pebbles, even the erosion, of which a few of the Inter-Trappean beds show slight signs, are not processes which demand lengthy intervals in a geological sense. An erosional unconformity between two marine beds is justifiably regarded as evidence of a considerable lapse of geological time because it involves earth movement, but none of the above entirely sub-aerial phenomena demands any tectonic disturbance.

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[174] "Current Science", p. 429, March, 1935.

There are other and more general reasons, however, for concluding that the Deccan Trap emissions extended over a protracted period. The thickness of the lava sheets which must in the past have totalled over 1½ miles, as well as their extent favours such a conclusion, and a comparison with the analogous Panjal Trap of northwest India, which the work of Middlemiss has shown strides an interval from the Middle Carboniferous to the beginning of the Upper Trias, makes it easily possible to conceive that the Deccan extrusions may have commenced as early as Upper Cretaceous times, and continued into the Tertiary. The outpourings of the Plateau Basalts of northwest Europe, if rightly correlated with each other, afford another example of protracted volcanic extrusion of a basic character, for they commenced in the Oligocene and have persisted till historic times. Another point of common resemblance is the tendency shown by such igneous outbreaks to change their locality, beginning characteristically in one area and finishing in another. The geographical shift of volcanic disturbance was comparatively small in the case of the Panjal Volcanic outbursts which began in the Marbal area, extended to the Lidar valley, later to the Nagmarg area and eventually to the country northeast of the Wular Lake and elsewhere. A similar shifting of the centre of disturbance seems to have affected the effusions and intrusions of northwest Europe; the basalt flows of Antrim, Mull, Skye and adjacent islands are of Oligocene age, but the centre of this volcanic activity appears to have moved to Iceland where alone it still survives. It would be no strain on our credulity, therefore, to suppose that the Deccan disturbances began in the Rajmahal hills, spread westwards through country where it is impossible to distinguish between Rajmahal dykes and Deccan Trap dykes, and ended either in the Bombay Presidency or in some region farther west now covered by the Arabian Sea.

If we omit the Rajmahal flows and dykes, we have the evidence such as it is of the Lameta fossils of Jubbulpore, that eruptions of the Deccan Trap (*sensu stricto*) were taking place in this area either soon after the Turonian or soon after the Lower Senonian. The marine infra-Trappean beds of Rajahmundry are of Maestrichtian age and the lowest trap of that particular locality cannot be older than Maestrichtian and is more probably early Tertiary. The Bagh beds, as we have seen, may correspond to any part—or perhaps even to the whole—of the sequence from lowest Cenomanian to Upper Senonian. There is a general though slight unconformity between the Trap and the marine Bagh Beds of the Narbada valley, due to subaerial erosion of the latter; in a few localities the Bagh Beds show signs of having been disturbed before the extrusion of the lowest traps. The basal traps of this region might thus be of any age from Cenomanian to Maestrichtian; they might be of the same age as the lowest-lying traps of Jubbulpore, but the evidence is more in favour of a somewhat younger age, a deduction which fits in with the suggestion of a westward migration of the volcanic activity. Farther to the westward, in Cutch, the Trap series rests unconformably upon the Umia beds (? Purbeckian to Neocomian), except at Ukra hill where it overlies beds of Aptian age.

Before leaving this question it is worthwhile reminding ourselves again that the above conclusions depend to some extent upon the Lametas being truly Infra-Trappean and not Inter-Trappean, a presumption which is not without an element of uncertainty. Our ideas regarding the chronological sequence of the basalt sheets, too, may require modification in the light of the fact that a flow may pass laterally into a sill and that in consequence a flow which, when traced laterally, is found to pass underneath other sheets of basalt, is not necessarily older than these. Cookshank notes the reluctance of the dykes to pierce the basalt sheets in places where there is reason to believe that the latter are of great thickness ; this would mean either that the passage of the dyke had been locally stopped altogether, or that it had squeezed its way horizontally as a sill and perhaps ultimately escaped as a flow from under the superincumbent basalt. The presence of an exposed Inter-Trappean bed lying upon one layer of basalt and passing under another, can be accepted as proof that the lower is the older of the two. Not only may the lowest-lying trap sheet in any particular area correspond to a trap higher up in the sequence elsewhere, but, if we reject the idea of a westerly drift of volcanic activity from the Rajmahal area, the earliest of the Deccan flows or dykes may not be exposed to view at all but may lie concealed somewhere beneath the enormous expanse of the visible traps.

It is possible that the so-called Lower Inter-Trappeans of different localities vary somewhat in age. That some of them belong to the Maestrichtian or some proximate stage receives some slight measure of support from the fact that in Persia and Baluchistan there are found mingled in the same bed with marine fossils of Upper Maestrichtian age threee Inter-Trappean species, namely, *Bullinus prinsepii, Cerithium stoddardi* and *Morgania* (*"Irania"*) *fusiformis.*[175] There is a close resemblance between the Indian lower Inter-Trappean and the Laramie group of North America ; the latter as now restricted, conformably overlies the Fox hills group with marine Cretaceous fossils and may itself include uppermost Cretaceous horizons.

According to Hora, the evidence of the fish scales found in the Inter-Trappean beds of the Satpura region, such as it is, favours the deduction that at the time these beds were being deposited India had separated from Africa.[176]

Concerning the age of the upper limit of the Deccan Trap, information is also somewhat vague and inconclusive, but there are indications and a certain amount of fossil evidence that the disturbance persited into the Eocene perhaps as late as the London Clay (Ypresian) epoch. Some of the evidence referred to lies in the more outlying occurrences of the traps, and to these attention is now directed.

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[175] E. Vredenburg, Rec. 36, 193 (1907).

[176] Rec. 73, 285 (1938).

Outlying occurrences.—In Surat and Broach the nummulitic rocks not only rest upon a largely denuded surface of the traps, but are in a great measure composed of materials derived from the disintegration of the lava flows, the lowest Tertiary beds consisting frequently of coarse conglomerates of rolled basalt fragments, whilst beds hundreds of feet in thickness, are chiefly composed of agate derived from the traps. This, although proving that great denudation of the volcanic rocks took place during the deposition of the nummulitic formations, does not necessarily imply a great break and an interval of disturbance prior to the commencement of the Tertiary period, because the traps, being of sub-aerial origin, were, unlike most sedimentary rocks, subject to erosion from the beginning of their formation. In Surat and Broach, however, the unconformity is distinct, and appears to show a great break in the sequence. The lowest Tertiary beds near Surat contain fossils which appear to be a mixture of middle and lower Eocene forms (Kirthar and Laki) ; it is doubtful whether the lowest Tertiary series, the Ranikot (Palaeocene) is present.

In Cutch the rocks forming the base of the Tertiary have been doubtfully referred to the Lower Ranikot, *i.e.*, to the Lower Palæocene, but might belong to the base of the Laki (Ypresian) ; resting upon the Trap, they appear in places to be conformable thereto, but elsewhere the junction between the two formations is marked by unconformity. The rocks in Cutch are so decomposed that it is doubly difficult to decide whether the volcanic material found in the Tertiary sediments is contemporaneous ash, or merely the detritus of eroded igneous rocks. The latter, however, seems to be most probable since the lowest Tertiary beds all appear to be of sedimentary origin, and no instance is recorded here of their intercalation with the lava flows.

One of the strongest arguments advanced in favour of a Cretaceous age was the presence of a so-called 40-foot band of basalt in Bor hill, western Sind, 700 fet below the *Cardita beaumonti* bed and interstratified among the Pab sandstones which rest upon the Hippuritic Limestone. Specimens of this rock, which was believed to be contemporaneous with its associated sediments, have been examined recently by Crookshank, who considers that the occurrence is in all probability an intrusion and not a flow. The rock is white in colour, and the supposed amygdales have characteristics incompatible with those of steam cavities in a solidifying magma ; the cavities in the Sind rock are irregular in shape, with ill-defined walls which show clear signs of reaction with the calcite filling the cavities. Crookshank concludes that the calcite is xenolithic, and the rock, which is composed mainly of felspar, probably one of the acid differentiates of the trap ; such differentiates are not uncommon and are always intrusive, so far as is known.[177]

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[177] 24th Ind. Sci. Congr., p. 464 (1937).

Higher up in the section just described, and resting with no visible discordance upon the *Cardita beaumonti* beds, is an important band of true basalt, overlain with the same absence of unconformability by the lowest beds of the Ranikot series. This has been traced for 22 miles, and the fact that it is always found in the same stratigraphical position is considered to be proof that it is not intrusive. The band has a thickness varying from 40 to 90 feet, but consists probably of two separate flows, the upper of which is somewhat ashy and contains scoriaceous fragments. The higher portion of each flow is amygdaloidal, the amygdales being filled with the green earth, quartz with trihedral terminations, and other minerals characteristic of the Deccan Trap geodes. Although lying upon marine beds, the trap shows no signs of being otherwise than of sub-aerial origin.[178] Assuming that this trap is a flow and not an intrusion, we have here definite evidence that the outpouring of lava continued until the early part of the Palæocene period; if it be correct to regard this trap flow as sub-aerial, the further deduction follows that its effusion must have taken place subsequent to the earliest Palæocene by an interval sufficient for the upheaval and probable erosion of the local sea-floor.

A more extensive, irregular belt of the Deccan volcanics is seen farther west in Las Bela State, stretching from the coast at Godani northwards into Jhalawan, where it is especially well-developed in the region surrounding Nal. These rocks appear to form a particularly inconstant member of the variable Upper Cretaceous, and occur both as superficial accumulations in the form of basalt flows, agglomerates and ash-beds, interstratified with marine sediments, and as intrusive masses. The latter are all basic, consisting principally of dolerites and serpentines, in connection with which occur valuable metallic ores.[179] The tuffs in places are highly fossiliferous but none of the fossils, with the exception of a very large nautilus, weathers out. These tuffs and flows for the most part lie between the Maestrichtian beds with *Cardita beaumonti* below and Nummulitic Limestone above, but a great thickness of massive, brown limestones with fossils that do not weather out, intervene in places apparently between the tuffs and the *Cardita beaumonti* beds.[180].

A non-intrusive band of basalt and serpentinous rocks, has been noted in the Upper Cretaceous of the Quetta-Bolan area of Baluchistan; it is described as of small thickness but wide extent.[181]

In the Fort Munro area of the Sulaiman range, overlying the Pab Sandstone and occurring between them and the surface leterite are some black sandstones full of volcanic material and crowded with fragmentary fossils. The latter do not seem to have been determined but the volcanic material is thought to belong to the Deccan Trap,

[178] W. T. Blanford, Mem. 17, 34-37 (1880).
[179] E. Vredenburg, Rec. 38, 196-197 (1909).
[180] E. Vredenburg, Rec. 36, 181 (1907).
[181] C. L. Griesbach, Mem. 18, 51 (1881).

and appears to be an ingredient of the topmost layers of the Pab Sandstone.[182] Since the latter formation corresponds in part to the *Cardita beaumonti* beds, and is believed to range from the Upper Campian to Maestrichtian and perhaps into the Montian, the above occurrence might be interpreted as an indication that the Deccan Trap disturbances had begun before the end of the Montian. The Pab Sandstone of Fort Munro, for the most part a massive white rock, is described as having here and there a flysch-like tendency; this flysch aspect has affected the succession in this part of India from Cretaceous to Oligocene times. Basalt beds and ashes are frequently found in the Fort Munro area between the Pab Sandstone and the Eocene.

Certain ultrabasic intrusions in other parts of the extra-Peninsular region, especially in northwestern India and Burma, are believed to be related to the Deccan Trap disturbances. These intrusions differ from those in the Archæan—the only other system of markedly different age in which ultrabasics form a special feature—in their more massive character, much greater size, and a much more advanced stage of alteration. While the Archæan peridotites form dykes of comparatively fresh rock and in Burma have yielded the gem olivines of Bernardmyo, those belonging to the Cretaceous-Eocene period are frequently of batholitic dimensions and in most cases almost completely serpentinised.

To the Deccan Trap period belong large basic and frequently serpentinised intrusive masses[183] of Upper Cretaceous age in the Upper Zhob valley and adjoining part of the Pishin district. The earliest evidence of contemporaneous igneous activity occurs in the form of ashes at the base of the Belemnite Shales; these are best seen in the upper Zhob valley, especially near Gwal, but whether they are to be regarded as an early phase of the Deccan Trap series is very doubtful.[184] In the serpentines, chromite occurs as veins and irregular segregations, the Hindubagh mines in 1930 yielding more than 25,000 tons. The basic masses consist of picotite-bearing saxonite (enstatite-peridotite)—the true home of the chromite—and dunite. The saxonite is rarely fresh, the olivine being nearly always at least partially converted into serpentine; this rock is locally traversed by dykes of dolerite.[185] Westwards these serpentines continue into the upper valley of the Pishin river; east and northeast they occur at intervals along the lower Zhob, even as far as the Tochi valley in Waziristan.

Sir Lewis Fermor, in considering certain aspects of the Deccan Trap flows of Bhusawal, has suggested how peridotite may have originated from the primary Deccan Trap magma by the concentration of olivine phenocrysts due to gravity. The same authority points out that under certain conditions pyroxenes may have formed

[182] E. Vredenburg, Rec. 36, 246 (1907).
[183] Rec. 31, 162-166 (1904).
[184] R. D. Oldham, Rec. 25, 19 (1892), Gen. Rep. Rec. 28, 8 (1895).
[185] Gen. Rep. Rec. 48, 12 (1917).

intratellurically in the magma-reservoir, and that, by differential gravitative settling of these phenocrysts in the reservoir, they may have caused the production and subsequent extrusion of olivine-gabbros, pyroxenites and perhaps saxonites. In this way the chromite-bearing serpentines of Baluchistan might be regarded as derived from ultrabasic variants of the Deccan Trap formed before extrusion. Although the Deccan Trap basalts do not themselves contain any chromium oxide, some of the bauxite which forms part of the lateritic deposits resting on and probably largely derived from the Trap has yielded a small amount of Cr_2O_3, varying from a mere trace up of 0·63 per cent.[186] Griesbach speaks of the association of igneous rocks not only with the Upper Cretaceous, but also with the "lower and middle part of the Eocene deposits"[187] basing his statement on nummulites found in the flysch facies of the Cretaceous and early tertiary. Unaltered limestones with Spintangi fossils (Upper Kirthar or Upper Lutetian) overlie the igneous facies of the northern Zhob and of the Kojak range. The acid rocks, chiefly of the granite family, which form part of the Khwaja Amran, are considered to be connected with the volcanic outbursts of this area and may have been among the earliest manifestations of igneous activity.

Volcanic rocks found in the Chagai district of Baluchistan and conspicuous by their dark colour and the greater height of their ridges, are believed by Vredenburg to be of Deccan Trap age. These consist principally of tuffs freely interbedded with marine sediments, and varying from agglomerates of large boulders to the finest ashes and porcellanites. In addition, volcanic material is found mixed in varying proportions in the sediments themselves. Real lava flows are seldom met with, and the large sheets of columnar diorite, which are abundant at Tozgi and near Ladis, are probably intrusive sills. In the Koh-i-humai a thick bed of Hippuritic limestone is seen resting on an extensive series of typical tuffs.

Rising through the Eocene, the sediments become more and more sparingly mixed with volcanic material; nevertheless a thick, coarse, volcanic conglomerate is found at Saindak immediately overlain by strata with typical Kirthar fossils. Sediments interbedded with the *Cardita beaumonti* beds contain an appreciable proportion of volcanic material, while great thicknesses of slate interbedded with limestone bands full of nummulites probably of Ranikot age are almost free from volcanic matter.[188] Among the igneous types mentioned besides basalt, are gabbro, augite-syenite (Ras Koh), quartz-diorite, aplite, limburgite, and dykes of basalt, dolerite, quartz-felsite-porphyry, etc., but there is some ambiguity as to which of these rocks belong to what is believed to be the Deccan Trap series, and which to a series thought to be considerably younger.

Up the Tochi river in Waziristan basic igneous rocks are first met with about 3 miles east of Mahomed Khel. Here limestones and

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[186] Rec. 58, 208 (1925).

[187] Gen. Rep. Rec. 28, 8 (1895).

[188] E. Vredenburg, Mem. 31, 195-197 (1901).

shales of Lower Tertiary (Palaeocene) age are seen resting abruptly but with no apparent unconformity upon a series of unfossiliferous shales; the latter are not only inter-bedded with the igneous rocks but in many places have been invaded and altered by massive intrusions thereof. Between two such sections, Upper and perhaps Middle Eocene beds are to be found resting directly upon the igneous rocks.[189] The igneous rocks have all undergone a considerable amount of alteration and, in addition, are much crushed and sheared. The most plentiful appear to be the gabbros and serpentines, the former with or without olivine and including enstatite altering to bastite; some of the gabbros show foliation, with the brecciation of their constituent minerals. Dolerite, trachyte and basalt are also present, the last amygdaloidal with calcite and zeolites in the cavities. Other rocks recognised are porphyrite, diabase, bronzitite and a bronzite-hypersthene rock. Some zinc ores brought back by F. H. Smith—calamine, smithsonite and zinc blende—prove that, as in eastern Baluchistan, metallic ores are associated with these igneous rocks.[190] Smith's tentative conclusion was that igneous action, in the form of intrusions and deposition of ash beds, began some time before the beginning of the Tertiary period, and lasted, with occasional variations causing interbedding, up to the end of middle Eocene times, but the evidence is not definite.

Serpentine and other igneous rocks, probably of the same age as the serpentines of Baluchistan, have been recorded by Coulson in Southern Waziristan, in contact with Upper Jurassic shales.[191]

The great outbursts of trap in the neighbourhood of Melkarez, Kandahar and the Shah Makhsud range, in southern Afghanistan, belong to the same suite as those of the Quetta-Bolan area, and therefore most probably to the Deccan Trap period. The rocks consist of basalts of many varieties, some of them amygdaloidal, the cavities being filled with agate and zeolities. In places the basalt is seen decomposed into a crumbling green earth. Associated with the lite basalt north of Kandahar is a serpentinous rock with veins and lumps of light green or yellowish chrysotile, used locally in Kandahar for the manufacture of beads for rosaries; chrysolite—clear olivine,—derived from some of the basalts, furnishes material for the more expensive kinds of beds and articles of jewellery. Numerous trap veins and dykes of very varying thickness traverse the adjoining Cretaceous rocks. In the Kokaran range the Hippuritic Limestone is greatly altered by trap intrusions.[192] According to Fox (private communication) the basaltic intrusions, not only of the country south of Kabul and the road to Jalalabad and the Khyber Pass but also of the Kandahar province, appear to be closely related to the Deccan Trap of India and are definitely of post-Cretaceous age.

The Dras Volcanics of Kashmir are equivalent in age to the Deccan Traps and have already been described (pp. 1316-1318).

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[189] F. H. Smith, Rec. 28, 109-110 (1895).
[190] H. H. Hayden, Rec. 29, 63-69 (1896).
[191] Gen. Rep. Rec. 72, 74 (1937).
[192] C. L. Griesbach, Mem. 18, 53-55 (1881).

Basic and ultrabasic intrusions, such as the olivine dolerites of the Simla area[193] have been recorded in various parts of the Himalaya. Some of these are described elsewhere; in some cases nothing is known of their age, in others they are the equivalents of the Dras volcanics.

The nummulitic and Cretaceous rocks of the Tibetan passes in Kumaon are traversed by enormous dykes of basaltic trap and serpentine, and have been greatly altered by the intrusions. Such intrusions occur in the Lesser as well as the Great Himalaya of this region and have been recorded also in the northwestern Himalaya; they are strongly developed in western and eastern Hundes.[194]

Altogether, therefore, the available evidence regarding the limits of the period straddled by the Deccan Trap disturbance is not very conclusive. Omitting the Rajmahal outbursts as belonging to the Middle Jurassic period, there is no valid objection to the view that the outpouring of the Deccan lavas commenced before the end of the Cretaceous, and there is good reason for supposing that the effusion of lava and ash continued across the Palæocene into the epoch of the Lower Eocene. The latter deduction is becoming more and more confirmed by a study of the Inter-Trappen flora.

Foreign simulations.—The Indian region was not the only part of Gondwanaland flooded with lava streams at or about this period. The rocks of the hills north of Aden, for instance, include basalts with or without olivine, and dolerites similar in every way to those of the Deccan. Apart from the products of Quaternary eruptions, there is here a volcanic series with interbedded aqueous sediments, overlying beds with Jurassic fossils. This volcanic series includes rhyolites, rhyolitic ash beds and breccias, and doubtful andesites, but is made up chiefly of basalts and dolerites, many of them identical with examples of the Indian traps. In them are the same geodes of agate, quartz, chalcedony, jasper, chert, opal and calcite; the first four of these secondary minerals are extremely common and their relics can be picked up, as they can in India, in large quantities from the surface of the ground.[195]

The corresponding outbursts of the Drakensberg Volcanics and Bushveld Amygdaloids in South Africa were on the same vast scale but took place at a much earlier epoch and date from early Jurassic times (Rhætic to Lias). Here occurred the same fissure eruptions of basalt, accompanied and followed by intrusions of dolerite in sheets and dykes over a very large area. Eruptions of the same age—the Serra Geral Eruptives—cover an enormous region in southern Brazil, Uruguay and Paraguay, and are present to a lesser extent in Argentina. The Kimberlite eruptives of uncommon type mark a widespread recrudescence of magmatic activity in South Africa, which is known to have been later than middle Cretaceous and therefore nearer the Deccan Trap period of India.

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[193] G. E. Pilgrim & W. D. West, Mem. 53, 56 (1928).
[194] C. L. Griesbach, Rec. 13, 91 (1880); C. L. Griesbach, Mem. 23, 45 (1891).
[195] E. Vredenburg, Rec. 38, 323 (1909).

In the Abyssinian plateau there are two main series of traps, of different age, the younger or Magdala series lying unconformably upon the older or Ashangi series. The latter is described by Blanford as strikingly like the Indian Deccan Traps in mineral character, the resemblances extending even to such minute peculiarities as the frequent occurrence of geodes, of agate or zeolite (usually white or orange-coloured stilbite), covered with green earth; both regions also include a peculiar porphyritic variety of basalt with tabular crystals of felspar.[196] The Ashangi basalts and dolerites are probably unconformable to the sandstones and limestones on which they lie, and are not older than Oolitic. Capping the inclined Ashangi basalts are the almost horizontal Magdala traps among which frequently occur thick beds of trachyte. Unfossiliferous sedimentary beds are interstratified with the lavas which include dolerites with amygdales occasionally enveloped in green earth. Examples of very similar extrusion are not wanting in the intermediate country of Arabia and Persia.

In a brief visualisation of the conditions which obtained during the Deccan Trap period, we start, at an epoch approximating that of the Turonian or soon after, with a land-mass separated or separating from Madagascar and South Africa and having a not very uneven ground-surface and a drainage, the bulk of which must have been eminently mature. From a sea somewhere west of Kathiawar a narrow gulf stretched eastwards up what is now the Narbada valley, past Bagh, covering perhaps the line of one of the faults or fissures which we know affected India towards the close of the Gondwana period. Many of the lakes which dotted this land seem to have been drained, and the deposits which had accumulated in them locally subjected to denudation, before the first outburst of lava took place. The effusions at first occurred at considerable intervals, during which small and very shallow lakes and marshes were formed, stocked with a rich assemblage of fish, mollusca, entomostracous crustacea and water plants, bordered by groves of palms, whilst a varied vegetation occupied the surrounding country. Some of these lakes and swamps may even have been caused by interruption to the drainage produced by the lava flows, but such interruptions do not seem to have been more than local and insignificant. There is evidence of the existence of insects and terrestrial reptiles, but hitherto no remains of mammals or birds have been found. Gradually the lakes seem to have disappeared, due probably to the increasing rapidity of the eruptions, and no further traces of life have been found until towards the close of the volcanic extrusions. The outpourings of lava came from no one particular locality but from fissures which opened successively from place to place. It is difficult to decide where the eruptions may have begun, especially as many of the earlier flows of trap may be completely hidden beneath the incubus of later extrusions. It is possible that at the end, as at the commencement of the period, the intervals between eruptions became longer, and the animal and

[196] W. T. Blanford, "Geology and Zoology of Abyssinia", 181-189 (1870).

vegetable life, which may have been seriously diminished during the rule of igneous conditions, resumed its old position under forms different from those of the earlier days of the period. Eventually, as the extrusive force became exhausted the basic magma was unable to lift or pierce the superincumbent masses of basalt, and extrusion and intrusion gradually ceased. The final phases are probably represented by the acid differentiates of the northwest and west. Further still northwest, parts of the volcanic country were depressed beneath the sea, and marine Tertiary deposits began to be formed from the detritus of the extinct volcanic effusions. A large proportion of the volcanic region, however, has remained almost undisturbed to the present day, affected only by suberial erosion and here and there by faults of no great magnitude.

THE SERPENTINE INTRUSIONS OF BURMA.

In Burma the Deccan Trap in its normal facies has not been identified, but sundry occurrences of basic and ultrabasic intrusions appear to belong to some phase of this period.[197]

The Andaman Islands.—Basic igneous rocks cover a considerable area in the Andaman Islands. Altered basic and ultrabasic instrusions of plutonic type occupy many of the hills and ridges of the central and eastern parts of Middle Andaman (including Saddle Peak and Saddle Hill), and occur in Rutland Island, and the Twins, the Cinque Islands and many other places.[198] These rocks vary from augite, enstatite and bronzite peridotite with picotite, to more felspathic types of the gabbro group ; occasional crystals of chromite are to be seen, and the olivine is often largely altered to a dark green serpentine with veins of chrysotile.[199] Dolerite dykes are seen here and there.

The jaspers, quartzites, calc-gneisses and porcellanic limestones of Middle Andaman Island, believed to be of Neocomian age and described in a previous chapter, owe their metamorphosed character to these intrusions which have penetrated them, and are very similar to those in Baluchistan.[200] In contrast the Tertiary rocks of Upper Ypresian or Lower Lutetian age show no signs of metamorphism, and the intrusion may be assumed to have taken place in either Cretaceous, Palaeocene or lowest Eocene times. Fragments and pebbles of serpentine, in fact, often form part of the Eocene conglomerates of the North Andaman Island.

Serpentines, gabbros and diorites are also found in the Nicobar group, a bronzite peridotite playing a prominent part among the basic intrusions on Batti Malv.

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[197] The occurrences of serpentine of Burma have been ably summarised by Dr. J. Coggin Brown (Rec. 56, 72-74 (1925).

[198] Rec. 59, 214 (1926) ; G. H. Tipper, Mem. 35, 204-5 (1911).

[199] J. Coggin Brown, Rec. 56, p. 70 (1924).

[200] Gen. Rep. Rec. 58, 37 (1925) ; Gen. Rep. Rec. 59, 215 (1926).

Basic intrusions are recorded in the granite and the Mergui argillities of Tavoy. They are restricted to certain localities, as for instance Danithagya, near Kandaung, between Kyaungdaung-maw-gyi and Mawshyi, and near Tavoy Point, and are extraneous in origin to the granite. They run irregularly and vary greatly in size, the largest observed, an exceptionally wide one, being 20 feet across. Generally they are fine-grained and their minerals are much altered and difficult to determine. Some appear to be basalt but they are of heterogeneous composition.[201]

Thaton.—Talc-schists have been found in various parts of Thaton and are thought by Leicester to have been derived from basic or ultrabasic igneous rocks.[202] In the same neighbourhood occur green epidiorites in which segregations of magnetite are found, and a highly altered basic rock which was probably a gabbro originally. Nothing is known regarding the age of any of these rocks.

The Arakan Yoma.—Intrusions of serpentine, sometimes decomposed to a steatitic rock, are not uncommon along the eastern foothills of the Arakan Yoma of the Henzada, Prome and Thayetmyo districts, especially among the Negrais beds. Generally they are irregularly shaped bosses of varying dimensions, but dykes also occur, especially to the northwest of Prome. The rock is a characteristic, dark coloured serpentine which, in the Prome district, frequently passes into gabbro with phenocrysts of magnesite. Hills formed of serpentine are distinguishable at a distance by their barrenness, and support little vegetation beyond grass and a few bushes. In the neighbourhood of some of the larger masses of serpentine the sandstones and shales are described as having been converted into chlorite schist and other metamorphic forms, but in some instances the contiguous rocks appear almost unaltered. In western Minbu Hayden states that nummulite-bearing limestones have been altered by outbursts of serpentine to such an extent as to make the fossils unrecognisable[203] but no intrusion has been detected elsewhere in Nummulitic rocks.

In the western part of the Henzada and northern end of the Bassein districts there are some twenty-three distinct and isolated occurrences of serpentine scattered over a length of twenty-six miles from north to south. They are situated along or close to the boundary between the Negrais rocks and the unaltered Nummulitic outcrop, a junction which was originally mapped as a fault but which is spoken of by Chhibber as one shewing overlap of the younger upon the older series. The largest of the serpentine masses is about 4½ miles long by perhaps ½ mile broad; the majority are less than a mile across. According to Chhibber[204] the serpentine is sometimes traversed by narrow veins of light green chrysotile or whitish steatite. In places the rock is schistose and shows signs of having

[201] J. Coggin Brown and A. M. Heron. Mem. 44, 189 (1923).
[202] Gen. Rep. Rec 61, 62 (1928).
[203] F. Noetling, Rec. 29, 74 (1896).
[204] Journ. Burma, Research Sec., 16. 176-199 (1927).

been affected by earth movement subsequent to the intrusion. The ancestors of the serpentine of this region vary from wholly or partially altered peridoties, saxonites and lherzolites to pure dunites: of these the most prevalent is saxonite, frequently associated with chromite or picotite. Other types recognised consist of amphibolite, hornbelnde-granulite and hornblende-eclogite, while a microdiorite is seen at times along the periphery of the intruded mass. The intrusions are thought by Murray Stuart to have altered the surrounding tertiary sandstones and shales as well as the Negrais rocks.[205] Chhibber supports this view and concludes that igneous activity extended over some period from late Cretaceous to early Eocene. According to the latter observer, there is in the shales around the intrusive masses a well-marked aureole of metamorphism in which have been developed typical chlorite and talc schists occasionally stained with iron salts; where the shales were carbonaceous, graphite has not infrequently been formed and pieces of impure graphite-schist are common in stream-beds near the contact. Where sandstones formed the country rock, the result was limited to baking, induration and crushing. An interesting feature of the invaded schists is the large amount of associated quartz the injection of which appears to be directly connected with the serpentine intrusion and the outcome of magmatic differentiation; veins of quartz are observable in the schists and boulders varying in size from a few inches to a few feet in diameter are found on the surface. A similar association has been noted in the northwestern Himalaya[206] where large spheroidal masses of quartz, in addition to numerous veins of the same mineral, occur throughout the serpentine itself. Another parallel is also seen in a much older association of such extremes as dunite and quartz in the Salem district of Madras.[207]

One of the several masses found N. W. of Prome forms a long dyke-like feature for about five miles, along the boundary between the Nummulitics and the older "Axial" beds; the latter appear to have been altered by the intrusion, while the Nummulitic rocks, although greatly crushed, show no evidence of contact metamorphsim. The largest of the serpentine masses in this part of the Yoma is a horse-shoe shaped intrusion, occupying the hill known as Bidaung, 35-40 miles west of Thayetmyo.

The steatite deposits of estern Kyaukpy, of Minbu and probably also of Pakokku, occur in serpentine. In the steatite mines of western Minbu, the mineral is of good quality and forms veins in the serpentine. Hayden records here dykes and intrusions of grey dolerite in great masses in the Chin Shales; this is the nearest approach to the Deccan Traps in Burma. Boulders of gabbro in the stream beds show that this rock is an accompaniment of the serpentine.[208]

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[205] Rec. 41, 252 (1911).

[206] F. Stoliczka, Mem. 5, 129 (1855).

[207] T. H. Holland, Mem. 30, 147 (1900).

[208] Rec. 29, 72-75 (1896).

According to Cotter, the beds below the basal Eocene conglomerate of the Minbu and Pakokku districts are of an ashy nature, while numerous outcrops of serpentine are to be found along this horizon.[209]

The native copper and copper ores found associated with the chromite of the Pakokku Hill Tracts and the Naga Hills, seem to have been introduced into cracks in the serpentine and, according to Coggin Brown, have perhaps been deposited from the aqueous solution which brought about serpentinisation.[210]

Boulders picked up by Bion in the gorge of the Upper Chindwin just below Kyaukse indicate that the serpentine bands in the neighbourhood of Sarameti continue to the northeast and probably cross the Upper Chindwin river a few miles above the Kyaukse rapids; one of the boulders was found to contain rhombohedra of magnesite.[211]

Further north, in Manipur State, a series of slates and indurated sandstones much resembling the " Axial beds " of the south, are penetrated by intrusive serpentine of the same type. R. D. Oldham has mapped a band of this rock 40 miles long and a mile or two in breadth, and also records some beds of volcanic ash on the slopes of Kachao which he assigned provisionally to the Mai-i or Cretaceous group.[212]

Corresponding to the Manipur band, the writer found serpentine further north still, in unadministered territory between the Naga Hills district of Assam and the line of high peaks which form the crest of the Yoma here. A dozen miles or more west of Sarameti peak (12,557 feet) serpentine forms a line of conical crag-crowned hills between Puchimi and Karami. The rock of which two or three bands were mapped, consists of a confused mass of massive and fibrous cerpentine; in other places the serpentine with its associated chrysotile and chlorite has to a large extent become schistose.[213] Several bands of serpentine were again found northwest of Sarameti, some of them along the line of strike of those betwen Puchimi and Karami. Other small bands were indentified north of Sarameti, near the village of Makwari. These igneous intrusions were found along the boundary of a conglomerate believed to represent the base of the Disang series of probably Tertiary age, with some more highly altered beds which may possibly belong to the Axial group; the conglomerate includes pebbles of the serpentine. Boulders of the following rock-types, believed to be at least in part responsible for the formation of the serpentine, were collected: horblende-enstatite-olivine gabbro; diallage-gabbro; serpentinised lherzolite (picotite-enstatite-diallage peridotite); and altered spinellid peridotite. In this area, contrary to experience in other parts of Yoma, the intrusions are situated to the west of the line of highest peaks.

To the far north La Touche records that the Dehing river brings down blocks of serpentine, in large numbers believed to be derived from the higher hills north of the river; material of this nature was

[209] Journ. Asiat. Soc. Beng., New Ser., 14, 409-420 (1918).
[210] Journ. Asiat. Soc. Beng., New Ser. 14, 73 (1918).
[211] H. S. Bion, Rec. 43, 244-5 (1913).
[212] Mem. 19, 217 (1883).
[213] E. H. Pascoe, Rec. 42, 258 (1912).

not observed *in situ* at the head of the river.[214] In the Nawngyang (Namyung) river, on the other side of the Patkoi range south of the Dihing, Murray Stuart found intrusions of serpentine in rocks identified as Disangs, but was of opinion that the latter had been metamorphosed by the former. Similar igneous intrusions were found by Stuart between the Nawngyang and Ta-ap rivers, and also in the Gedu river.[215]

Pockets of chromite were found by Bion in the serpentines of Manipur, and this mineral, according to Coggin Brown, is known from various localities in the Arakan Yoma and its extensions to the Jade Mines of Tawmaw.[216] H.S. Bion has suggested that the platinum and osmiridium which occur in minute quantities but almost universally with the placer gold of the Chindwin and its tributaries, may have been derived from the deposits of chromite associated with the serpentine intrusions.[217]

The Jade Mines.—The serpentine of the Tawmaw area is seen on both sides of the Uyu (Uru) Chaung in four surface outcrops, the total area of which cannot be less than 8,000 square miles. In one of these outcrops occurs the intrusive dyke of jadeite which has made the locality famous. With a general N.E.—S.W. trend, the dyke is 200 yards wide and over 300 yards long but varies very much in thickness;[218] it is worked by Chinese traders who use a primitive process of cracking the rock by fire. The serpentine hills of this area are all much alike, with steep sides crowned by long narrow plateaux; west of Nanyaseik there are several serpentine intrusions forming range upon range. Tawmaw is made up of a large mass of peridotite, partially or wholly altered to serpentine;[219] among the types represented are dunite, mica-hornblende peridotite, diallage-peridotite, diallage-perknite pyroxenite) and amphibolite, saussurite-gabbro and saussurite-hornblende gabbro. The serpentine is of normal type, with remnants of olivine altering to chrysolite, with crystals of magnetite, and with chromite in crystals, grains, irregular concretions and veinlets. Chromite is found disseminated throughout the serpentine but in no commercial quantity, and occurs as inclusions in the olivine of the parent rocks. Accompanying the serpentine in a few localities are bosses of a basic igneous rock belonging to the family of basalt and identified as a pyrite porphyry.[220] The adjoining Tertiary deposits are unaltered in aspect and include a conglomerate with pebbles of serpentine, quartz-pyroxenite, saussurite-gabbro and occasionally jadeite. A rock moderately plentiful in small pieces at the jadeite mines is a dark green chromite-bearing member of the epidote group, to which Bleeck has given the name of Tawmawite.

[214] Rec. 19, 114 (1886).
[215] Rec. 54, 402-3 (1922).
[216] Rec. 56, 72 (1924).
[217] Rec. 43, 247 (1913).
[218] Gen. Rep. Rec. 62, 55 (1929).
[219] Gen. Rep. Rec. 62, 108 (1929).
[220] A. W. G. Bleeck, Rec. 36, 255-258 (1907).

Jadeite is regarded as a member of the pyroxene group. The dull green colour often affected by the mineral is due to the presence of iron compounds, but the brilliant emerald green so characteristic and so much prized is the result of the presence of chromium. The jadeite is accompanied by albite, the combination forming a dyke rock which has intruded the serpentine, producing signs of contact metamorphism, the most conspicuous of which is the development of new minerals such as chlorite, clinozoisite, tawmawite, chloritoid and soda-amphibole ; along the zone of contact the jadeite-albite rock often assumes a banded and schistose character caused by numerous parallel inclusions of amphibolite. The original intrusive is believed by Bleeck to have been a nepheline-albite rock, the jadeite having been developed under very high pressure by the combination of one part of albite with one part of nepheline ; the mineral nepheline has been repeatedly recorded in jadeite. Jadeite has been found at Mamon, six or seven miles south of Tawmaw as boulders in the alluvial deposits of the Uyu Chaung, along the upper reaches of which it has been observed as far as Sanka ; seven or eight miles still further south the mineral occurs as boulders in a Tertiary conglomerate at Hweka.

Altered peridotites have been traced as far south as Kawabum and are found again to the east and north of Kamaing. South of the latter town, a schistose crystalline complex occupies the high land which forms the N.E.—S.W. watershed between the Indaw and the Nam Yin Chaungs[221] and has also been observed in the range of hills on the southeastern side of the Nam Yin from near the junction of this tributary with the Mogaung Chaung southwestwards. It includes types which can be matched in the Jade Mines area, the predominant member being a phyllitic schist, graphitic in places, and with garnet crystals sometimes altered to pseudomorphs of iron oxides. These schists, which are highly cleaved, puckered and folded and fall to pieces easily on weathering, are extensively injected by veins, lenses and stringers of quartz. The schistose series includes a quartzite. Small intrusions of schistose amphibolite and epidiorite, as well as serpentinised peridotites and serpentines, are recorded. To the north-west of the Indaw Chaung granite is seen intrusive into a limestone, and old mine workings are seen ; here also diorite, gabbro and serpentinised peridotite are present. Much further survey work is necessary before the full extent of the belt of Ruby Mines rocks is known.

Bhamo and Myitkyinia.—In Myitkyinia and Bhamo, parallel to the general strike of older rocks, are long strips of igneous rocks, intruded, according to Griesbach, into fissures of dislocation.[222] These intrusions are accompanied by numerous dykes which also penetrate the neighbouring formations, the more basic varieties in certain localities carrying the mineral jadeite.

[221] Gen. Rep. Rec. 69, 48 (1935).

[222] Gen. Rep. Rec. 26, 8 (1893).

In western Bhamo, at both ends and also in the middle of the Second Defile of the Irrawaddy, are outcrops of serpentine which show intrusive relationship towards adjacent Cretaceous sediments.[223] At the lower end of the defile these intrusions terminate the Cretaceous abruptly on both banks of the river, and at the upper end on the right bank; in the middle portion they separate an outcrop of old sediments of possibly Chaung Magyi age from the Cretaceous. The neighbouring late Tertiary rocks are not intruded. The intrusions consist mostly of dark green serpentine, but less altered specimens point in some cases to a doleritic ancestor. This serpentine outcrop may be continuous with that noted between Bhamo and Sinbo further north.

Another line of intrusion is reported to occur in a N.-S. direction along longitude 97°30′ as far as the "Confluence" between the Mali Kha and the Nmai Kha.

Kachin.—In the Hukawng valley, altered peridotties and serpentines have been found by Chibber encircled by crystalline schists similar to those of the Jade Mines area[224]. The graphitic and chloritic schists, which are highly crumpled and flexured and extensively injected with quartz veins, are accompanied by limestone.

Kalaw, Southern Shan States.—Porphyry and dolerite intrusions into the Kalaw Beds cannot be earlier than Jurassic and may possibly be of the same age as the intrusions now under consideration.

Malaysia.—Intrusions of gabbro, norite and serpentine of unknown age are recorded in the Malay States.

[223] E. L. G. Clegg, Rec. 71, 358 (1937).
[224] Gen. Rep. Rec. 65, 78 (1931).

CHAPTER XXVIII.

EXTRA-PENINSULAR GRANITIC INTRUSION.

Number and age of the granites. I. **The Himalaya and its continuations**; General considerations; The Central Gneiss; Indications of age; The Chor Granite; Occurrences in the Sutlej valley; Chamba State and Dalhousie; Tehri Garhwal; British Garhwal; Almora; Sikkim; Nepal; Everest area; Bhutan and southeastern Tibet (Tsang and U); Aka Hills; Dafla Hills; Miri Hills; Miju ranges; Singpho Hills; Kashmir; North-West Frontier; Baluchistan. Recapitulation. **II. Burma**; The Tawng-peng Granite; Bawdwin mineralisation; The Mohochaung Mines. North Hsenwi; Hsipaw State; Mandalay; Older granites in Yamethin; Mawson (Bawzaing); Mawk-Mai; Pindaya; Myitkyinia; Bhamo; Putao; Lower Chindwin; Yunnan. Tavoy Granite in Tavoy; Pegmatites and Quartz veins. Mineralisation. Tavoy Granite in Mergui. Amherst. Thaton. Toungoo-Salween. Karenni. Yamethin. Yawnghwe State. Yengan, Kyaukse and Meiktila. The Wolfram and Cassiterite period. Comparison of the Burmese granites with those of the Himalaya.

Number and age of the granites.—The Archæan and other pre-Cambrian granites which make up such a large proportion of the Peninsula have been considered in the early chapters of this book. Since the early Palæozoic era no intrusion of granite seems to have invaded the Peninsular region as strictly defined. The only approach to such an intrusion is seen in the white quartz reefs which form such a conspicuous feature to the north west of Dhanbad and elsewhere in the neighbourhood of the Jharia coalfield. These reefs, which show no trace of metalliferous minerals, are believed to be younger than the Lower Gondwanas and in places appear to be related to some of the larger faults that cross the field. They have been largely quarried for road-metal and railway-ballast.[1]

In the Extra-peninsular regions it is otherwise, but the copious granitic intrusions found there have never received the attention they deserve and our knowledge thereof is vague and scanty. Not only is it beyond question that these regions include intrusions later than the early Palæozoic, but the great bulk of the granite in these parts is probably younger than Devonian.

I. THE HIMALAYA AND ITS CONTINUATIONS.

General considerations.—The main range of the Himalaya, with its line of maximum peaks, is occupied by gneiss or granite which, with its associated crystalline rocks, forms a continuous but irregular zone along the axis of the chain, and separates in a general way the old Himalayan sedimentary systems belonging to the peninsular region from those of the Tibetan zone to the north. Formerly the granite of the high peaks was thought to comprise two kinds, a foliated type with biotite, and a non-foliated type containing muscovite, tourmaline, beryl and various accessory minerals; the latter

[1] C. S. Fox, Mem. 56, 19 (1930).

was considered to be the younger and was reported to be often intrusive into the former. Much of the gneiss along the central range, however, is known to be paragneiss, while some of it is a hybrid rock formed by the injection, on a variable scale of intimacy, of a granitic magma into a fissile series of ancient sediments. Unmixed granite is more plentiful on the Tibetan side of the main range, where it forms a granite zone among the Tibetan sedimentaries or between them and the maximum line of uplift. Of this northerly granite very little is known.

In the main range, and to some extent in the Lesser Himalaya to the south, a prominent part is played by a granitic intrusion which has been called the "Central Gneiss" or "Himalayan Granite". Again very little is known as yet as to the age and relationships of this rock which, gneissose or otherwise, hybridised with other rocks or unadulterated, forms such a large proportion of the core of this mountain system. Besides this predominant intrusion, for which a late palæozoic age has recently been suggested, there are present granites which are believed to be of different ages.

The Chor granite was at first suspected of being Archæan in age but, according to a later view, is equated with the Central Gneiss. To maintain, however, that Archæan gneisses are entirely absent from the Himalayan chain would be as rash as to claim the definite identification of any exposure thereof. If Archæan sediments corresponding to the peninsular Dharwars, are present in the Himalaya, a premise which has not yet reached the stage of proof, we might expect them to be accompanied by representative of some of the Archæan granites such as the Peninsular. The statement that the Great Himalaya of Kumaon harbours a granitic gneiss older than the Central Gneiss and intruded thereby[2] is probably due to what we may suspect to be a too rigid interpretation of the limits of the Central Gneiss. There is, however, evidence of an earlier granite in the arkose, containing both plagioclase and tourmaline, found at the base of the Jaunsar series (? Devonian) of Simla and Chakrata; the presence of the felspar alone might be considered inconclusive, but the joint occurrence of felspar and tourmaline is more definitely suggestive of a granite source. Intrusive into a succession which included Upper Silurian strata in the western K'un-lun mountains, De Terra has recently found a granite, for which he suggests a Lower Devonian age[3] but which might presumably be later; granites of a similar kind but of post-Carboniferous age are reported to occur only a few miles south of the K'un-lun. Arkoses in the Tal series (Jurassic-Cretaceous), with microcline and tourmaline, indicate a granite derivation, a conclusion supported by the considerable size of some of the felspar pebbles in the Tal sediments[4]; the age of this granite might be anything up to the Tal period. A highly sheared and mylonised granite found by Auden in the Nela (Lamkaga) valley,

[2] C. L. Griesbach, Mem. 23, 43 (1891).

[3] Geol. Forsch, im Westl. K'un-lun und Karakorum—Himalaya, p. 47 (1932).

[4] J. B. Auden, Rec. 66, 469 (1932).

to the north of Harsil, in Tehri Garhwal, must be of pre-Miocene age if the earliest thrusting movements are rightly dated as Miocene. This granite, which has altered the overlying metamorphic rocks, has been sheared and mylonised throughout a width of 150 feet at right angles to the plane of contact, with the development of marked schistosity and the destruction of the phenocrysts.[5] Another highly sheared granite intrudes the Dalings of eastern Nepal and therefore also antedates the thrusting. A hornblende granite in the upper Burzil valley of Kashmir is described by Wadia as intruding the Dras volcanics which contains thin intercalations of an *Orbitolina* limestone[6]; this intrusion, therefore, could not have been earlier than Upper Cretaceous and would have to be regarded as post- Palæocene if the similar strips of Dictyoconoides-bearing limestone are true intercalations and not folded up with the Dras rocks. Granodiorites, some of them containing hornblende, occur in the lower Dras valley of Kashmir, and are intrusive into the Cretaceous-Eocene Dras volanic series. Auden thinks that this intrusion is probably the same as the Ladakh granite, which appears to intrude the Dras Volcanics and to contain xenoliths thereof (Private communication). In petrographic character this hornblende granite of Kashmir is said to be very like a granite of the Everest region[7] which injects not only beds correlated with Dalings and a limestone of Permo-Carboniferous or Carboniferous age, but also Jurassic strata; both Heron and Wager suggest a Tertiary age for this granite.[8] Belonging to the same suite, presumably, is the massive muscovite-tourmaline granite, found by wager in the upper Chumbi valley around Gantsa. Along its northern edge this granite injects and metamorphoses not only the ancient Dalings but a limestone—the Mount Everest Limestone—believed to be Carboniferous or "Permo-Carboniferous" age, and was observed by Hayden to have altered the sediments of the Dothok series (Trias). Since it is quite uncrushed, Wager concludes that this granite must have been intruded after the compressive Tertiary mountain-building movements.[9] The Chumbi river has cut a gorge through this rock.

The hornblende-albite-sphene granite of the Kyi Chu in southern Tibet (Tsang and Ü) was found by Hayden to be definitely not older than Upper Cretaceous.[10]

It might be expected that the profound disturbances which folded and overthrust the rocks of the Himalayan chain would have been accompanied by igneous instrusions on an extensive scale. It was

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[5] J. B. Auden, Rec. 71, 431 (1936).

[6] Rec. 72, 151 (1937).

[7] A. M. Heron & D. N. Wadia, Rec. 66, 224, note 2 (1932).

[8] A. M. Heron, Rec. 54, 220-224, (1922); L. R. Wager, Nature, p. 976, 23 Dec. (1933).

[9] H. Ruttledge, Everest 1933, 321.

[10] Mem. 36, 183 (1907); Hayden thought that the foliated biotite granite and the associated tourmaline granite of Tsang and Ü was probably not older than Eocene; this granite, however, is continuous with the axial granite of the Himalaya, *i.e.*, the Central Gneiss, which Hayden also considered to be of Tertiary age [Burrard & Hayden 'The Himalayan Mountains and Tibet', 1st Ed. p. 219 (1907)], but which is probably much older (Vide infra).

only natural that the gneissose granite of the crystalline axis, the Central Gneiss as it was called, should be believed to play this role, but one is tempted to suggest that the expectation was farther to the belief. Be this as it may, the bulk of the granite exposed in the main range and on the Indian side of it would appear to have been intruded long before the commencement of the Himalayan folding and long before the Tertiary era, if we are to accept the somewhat inconclusive evidence available. Some of the earliest Himalayan granites to come under observation were those occurring in laccolithic masses in various parts of the Lesser Himalaya. One of these was the Dalhousie Granite and in the early eighties of last century that enthusiastic petrographer, General McMahon stated that he thought it probable that "in the Dalhousie area, the intrusion of the gneissose-granite took place at the close of the Eocene, or early in the Miocene period".[11] This was combatted by C. S. Middlemiss who pronounced in favour of a period antecedent to the Trias and perhaps even to the Infra-Trias, pointing out, among other things, the absence of any violent disruptive phenomena which could be proved to have resulted from the intrusion of the gneissose-granite of the crystalline axis, as manifested in its position among the metamorphic crystalline schists.[12]

Tertiary granite exposures, however, are by no means absent from the Himalaya, and it is not at all unlikely, that such occupy extensive tracts along the Tibetan side of the main range. As remarked by W. D. West[13] the youngest type of Himalayan granite appears to be a tourmaline-granite of very late Kainozoic age, though the presence of tourmaline, like that also of garnet, is not restricted to it but is frequently found in the older suite of intrusions. Hornblende is another mineral which appears to be characteristic of the granites known to be of Tertiary age, but here again it does not seem to be confined always to rocks so young. Whether the granite zone on the Tibetan side of the main range is the expected intrusion which accompanied the Tertiary folding and fracturing, future work may disclose, but the present position may be summarised by the statement that, although we may still expect to find Tertiary granitic intrusions on a large scale, the actual evidence of such so far obtained is not as widespread as it was at first supposed.

The Central Gneiss.—The most extensive set of granitic intrusions in the Himalaya, that which Stoliczka called the Central Gneiss, stretches from Hazara eastwards through Kashmir to Garhwal and beyond, composing much of the mountains of Bhutan and the unknown regions to the east thereof. A very general description of the axial granitic rocks of the Himalaya is that of a foliated gneiss intruded by a younger granite. This has been expressed by McMahon in the statement that the "Central Gneiss" of the Sutlej, lower Spiti and elsewhere, is everywhere more or less riddled with intrusive dykes and veins of light-coloured oligoclase granite.[14] Speaking of the

[11] Rec. 16, 192 (1883).
[12] Mem. 26, 274 (1896)
[13] Current Science, p. 288, (1935).
[14] Rec. 15, 48 (1882).

great peaks Hayden expresses himself as follows.[15] "Of the granite there are at least two varieties, a foliated rock composed essentially of quartz, felspar and biotite, and a younger non-foliated form containing, in addition to quartz and felspar, muscovite, black tourmaline, beryl and various accessory minerals. The former variety was long regarded as a sedimentary rock which had been converted by heat and pressure into gneiss, but its truly intrusive nature was recognised by the late Lieutenant-General C. A. McMahon[16] who proved conclusively that the great central gneissose rock of the Himalaya was in reality a granite crushed and foliated by pressure. This rock is frequently pierced by veins of the second or non-foliated variety, and where these run parallel to the foliation planes, they lend to the series a deceptive appearance of bedding and cause it, when seen from a distance, to be mistaken for a mass of stratified deposits. This is a common character of the higher peaks and may be noticed in many of the granitic masses of the Great Himalaya range ".

In addition to the two dominant types, corresponding evidently to two different phases of intrusion, others are occasionally noticeable. In this work the term Central Gneiss or Granite will be used for all, but it would be premature to state that no appreciable lapse of time occurred between the intrusions. It is, furthermore, not unlikely that some of the rock mapped by old observers as Central Gneiss is in reality a complex made up of ancient schists and intimate intrusions of a granite magma corresponding to that of the Central Gneiss.

Everywhere in the mountains the parallelism in this rocks as regards foliation and the margins of its beds has been remarked on. In many places it occurs in great beds or laccoliths which may be followed in their course through a mountain massif, just as we might follow a thick stratum of some sedimentary rock or an igneous flow. The intrusion has perforce followed the lines of least resistance, which were the divisional planes of the rocks among which it was squeezed[17] and has shared in the main disturbances responsible for the uprise of the mountain chain. The greater and more continuous masses along the main range, and still more the smaller detached areas in the Lesser Himalaya, are surrounded by zones of contact metamorphism in the invaded schists. In contrast to the gneissic rocks of the peninsula, the principal phase of the Central intrusion is remarkably uniform throughout the Himalaya, in petrological character, in the range of the felspars, in the ferromagnesian constituents and in the grain of the rock.

Many of the ingredients, some of them in a very fresh condition, of the tertiary Siwalik sandstones in the Himalayan foot-hills, have been derived from granite; whether they have come from the Central

[15] S. G. Burrard & H. H. Hayden, "The Himalayan Mountains and Tibet", 44 (1907).

[16] Rec. 15, 44 (1882); Rec. 16, 129-133 (1883).

[17] C. S. Middlemiss, Mem. 26, 274 (1896).

Gneiss or from younger Tertiary intrusions or from both, it is idle to surmise until more is known of these various igneous rocks.

Ramifications from the central mass have been sent out and have been recognised, for instance, in the Chamba area of the Punjab, in the Chaur area between Simla and Chakrata, in the Lansdowne area, in the hill at Almora, in Nepal, in the Darjeeling district, and in the Chumbi valley of Tibet. In view of their general similarity the conclusion that they are identical seems justifiable. For the most part, these outlying intrusions form as it were a second, lower parallel belt of granite, and a capping to many of the higher ridges south of the main chain in the Punjab and Garhwal sections of the Himalaya; some at least of these outlying occurrences have been overthrust together with their country rocks upon younger formations. Until recently, the intrusion of the Central Gneiss was regarded as of Tertiary age and assumed to have been the plutonic accompaniment to the orogenic folding which commenced in late Cretaceous times and continued through the Tertiary, Pleistocene and Recent periods to pile up the range. From descriptions and comparisons made at various times by various observers, the granite masses suspected of belonging to the Central Gneiss intrusion are the following: two occurrences of granite recently described by De Terra in the western Kun-lun ranges; the Tankse granite of the Karakoram area,[18] the granite of Hazara, including the Kagan valley; the granite around Nanga Parbat, in Gilgit and in other parts of Kashmir; the granite of Lansdowne, Chamba and Dudatoli, as well as the main mass in Kangra and Bashahr (all in the Punjab); the Chor massif near Simla; granites lying in the Saraswati and Arwa valleys of the central Himalaya, and perhaps forming some of the peaks of this section of the chain (? Kamet); possibly the granite occurring as sills in the paragneisses which build up many of the peaks of the main range in Tehri and Kumaon, such as Bander-punch, Gangotri, Kedarnath, Trisul, Nanda Devi and probably Badrinath; the igneous elements of the gneiss of Nepal, Sikkim, Chumbi and other neighbouring parts of Bhutan and southeastern Tibet. It is difficult to fix the precise age of the intrusion and all that can be said of is that it seems to have taken place at some time between the Cambrian and the end of the Carboniferous and quite possibly during the early part of the latter period[19]; the limits of its age may vary slightly from place to place. Although now found in the Himalaya, and in this sense Himalayan, the granite under consideration is thus suspected of having been intruded before the movements responsible for the formation of the chain; the question of its age, however, cannot be regarded as settled.

Indications of age.—J. B. Auden was led to an enquiry concerning the age of the Central Gneiss by the discovery that a granite pebble found in a breccia at the base of the so-called "Purple Slate series" of Garhwal was lithologically identical with a granite mass cropping

[18] Geol. Forsch. im Westl. K'un-lun and Karakoram—Himalaya, Berlin (1932).
[19] J. B. Auden, Rec. 67, 414 (1933).

out in the Arwa valley and forming an integral part of the Central Gneiss suite.[20] A certain portion of the Purple Slate series is not only extremely like the Jaunsars of Chakrata and Solon, but occurs just below a boulder bed overlying the Jaunsars in the more western sequence. The age of the Blaini is in all probability uppermost Carboniferous, and the Jaunsars are, therefore, quite likely to be either Carboniferous or Devonian. Accepting the above correlation, the breccia at the base of the Purple Slates cannot be younger than Carboniferous, nor can the granite pebble it contains. nor can the granite from which the pebble was derived.

Granites, granitic gneisses and pegmatites of many varieties stretch from Musapani in the Saraswati valley to Ghastoli and up the Arwa valley. It was among some porphyritic and non-porphyritic granites found along the Arwa valley extending from near its western extremity as far as the 16,300-foot base camp of the 1931 Kamet Expedition, that the pebble in the breccia was matched. The most striking feature of the rock in question is the prevalence of sodic plagioclase in the form of albite-oligoclase ; microperthite and anorthoclase also occur, while the biotite, which is more common than muscovite, is very generally chloritised. These characters are all seen in both the pebble and the *in situ* rock. The commonest type of granite found in the Arwa valley and forming part of the Central Gneissic suite is a white, moderately fine-grained rock, containing quartz, felspar, muscovite, biotite, and often abundant tourmaline, the minerals showing no parallelism.

The Arwa granites belong to Griesbach's "newer suite", *i.e.*, to the Central Gneiss, which is described as penetrating the older granite gneiss and schists, the Haimanta rocks and the Vaikritas, sometimes in a perfect network of veins, at others swelling out to immense massifs ; in places the invaded rocks have been metamorphosed, the Haimanta clay slates, for instance, to garnetiferous, micaceous schists. Within the belt of this "newer suite", however, Griesbach included nearly all the great peaks of this portion of the Himalaya, several of which—Nanda Devi, Trisul, Kedarnath, Gangotri and probably Badrinath—are now known to be built up for the most part of para-gneiss but include intrusions of the Central ("Newer suite") Granite.

The Chor Granite.—The Chor Mountain ((11,966 feet), a conspicuous feature in the landscape southeast of Simla, is a granite intrusion of a laccolithic nature which has found its way into a syncline of Jutogh beds.[21] This syncline and the granite intrusion within it have been overturned towards the southwest by a powerful movement from the northeast, with the result that, while the Jutogh beds dip away from the granite in a northeasterly direction along the northeastern margin of the *massif,* they are seen along its southwestern border dipping in the same direction at about 30° beneath the granite, whose foliation and boundary confirm generally to the strike of the Jutoghs.[22] This general structure is complicated by minor details,

[20] Rec. 66, 461-471 (1932).
[21] G. E. Pilgrim & W. D. West, Mem. 53, 52-56 (1928).
[22] Gen. Rep. Rec. 65, 129 (1931).

and towards the east the dip of the Jutogh beds and the foliation of the granite become nearly vertical. The Chor-Granite contains numerous inclusions of schist and quartzite, and is undoubtedly a plutonic intrusion into the Jutogh beds. Some absorption of the latter seems to have accompanied the invasion, for the boundary of the granite is described as cutting across the bedding of the adjacent sediments.[23] In one place also the matrix of the granite was observed to be highly hornblendic, a condition due, in the opinion of Oldham, to the absorption and replacement of hornblendic rocks. The metamorphosing effects of the Chor intrusion upon the Jutogh beds have already been described (p. 303) and the possible former extension of the granite over the Simla area mentioned.

The Chor-Granite is a coarse and nearly always foliated rock, having a specific gravity of about 2·70. Megascopically it, as well as the Hazara and Lansdowne granites, even when unfoliated, differs markedly from the granites found in the Saraswati and Arwa valleys[24]; the albite-oligoclase felspar, however, so characteristic of the Garhwal rocks occurs, often extensively, in the granites of Chor, Hazara and Lansdowne. The Chor rock is a porphyritic biotite-granite with abundant phenocrysts of orthoclase which are almost invariably twinned on the Carlsbad law, often attain a length of two inches, and commonly contain abundant inclusions of the groundmass, numerous little crystals of zircon and some apatite. The felspars of the groundmass are chiefly orthoclase and oligoclase. Quartz is the most abundant mineral, occurring in strings of small grains which, together with the mica, sweep round the phenocrysts, enclosing them as lenticles. The rock is rich in biotite which is the predominating mica, though rarely occurring in large crystals. Muscovite is subordinate in amount, sometimes in medium-sized flakes, sometimes as a fine serictic aggregate. Sphene is plentiful, and another almost universal constituent is a mineral provisionally identified as epidote with a nucleus of allanite.[25] The foliation in the rock is thought by Pilgrim and West to have been induced by its own intrusion and varies in degree. In the most foliated types the mica occurs in thin parallel strings or is closely wrapped round the orthoclase crystals which have lost their sharp outline and have assumed a rounded form, the result being a rock approaching an augen-gneiss.

Occurrences in the Sutlej valley.—Forty miles north of the Chaur peak, the axis of the Dhaoladhar range, which contains the main mass of the intrusion, a porphyritic gneissose granite of uniform characters over a wide area crosses the Sutlaj here also, invading the garnetiferous mica schists and the quartzites of the Jutogh series. It is described by West as forming the high ridge in Mandi State further northwest, rising to 11,000 feet in altitude in places and visible from Simla; it is bordered by an acid phase locally rich in tourmaline. Five miles to the south, but on the north bank of the Sutlej

[23] R. D. Oldham, Rec. 20, 159 (1887).
[24] J. B. Auden, Rec. 66, 464, note 1 (1932).
[25] G. E. Pilgrim & W. D. West, Mem. 53, 53-4 (1928).

is a prominent sill of *augen* gneiss probably belonging to the same intrusion.[26] Varying from 1,500 to 3,000 feet in thickness, it is intruded concordantly into the Chail beds and crosses the Sutlej near Luhri, where it is almost horizontal. This band resembles exactly, both in appearance and in position, the outer band of gneiss mapped by McMahon to the west of Dalhousie hundred miles or so further northwest, and is probably present also in north Chakrata. Higher up the Sutlej and further northeast, the Central Gneiss is again met with and again traversed by the river, in the valley of which it is seen as far up as Jangi. At the Wangto bridge it is an oligoclase granite, but higher up it gives place to a complex series of mica-gneisses, kyanite-schists and garnetiferous mica-schists, with basic igneous rocks and much intrusive granite. Some of these beds resemble those of the Vaikrita system, but similar schists in the Spiti river below Chango pass laterally into phyllites and clay slates corresponding to the Middle Haimanta and belonging, therefore, to the Cambrian. Similar schists occur between Spueh and Hango in this section of the Sutlej, and between Asrang and Jangi highly altered staurolite and kyanite-schists are observable where the intrusive biotite-granite is found in contact with the Cambrian slates.[27] Between Jangi and Shipki in the Sutlej valley numerous masses of the granite occur in the altered Cambrian slates; here the intrusive rock is described as very pure and free from accessories, consisting mainly of quartz, orthoclase and biotite, with a little muscovite and plagioclase. Higher up the river, the gneiss again comes in at Shipki. The predominant rock through which the river has here eroded its course is a grey hornblendic gneiss; in the gorge south of Shipki the right side of the Sutlej valley forms an immense and almost perpendicular wall composed of the hornblendic gneiss seamed with light-coloured veins of albite-granite contrasting strongly with the darker parent rock.

The high ranges bordering Spiti on the south, west and east are composed chiefly of granite, the commonest form being a biotite-granite ranging from a fresh rock of medium grain to a foliated, gneissose variety with large porphyritic felspar crystals.[28] At Lio in Bashahr it has penetrated and altered Silurian limestones in numerous veins, the chief product of alteration being wollastonite which occurs in great quantity above Lio. Associated with the biotite-granite in the Sutlej and Chandra valleys and in the ranges between Kulu and Spiti are numerous veins of albite-granite or pegmatite containing large quantities of tourmaline, muscovite, beryl and, locally garnet and kyanite; the trihedral prisms of tourmaline in the Chanda valley are sometimes a foot in length, though smaller hexahedral prisms are commoner. The beryl is very brittle and occurs in crystals frequently several inches in length.[29] The biotite-granite is found along the Spiti river, and at Changrizang in Bashahr

[26] Gen. Rep. Rec. 72, 80 (1937).
[27] R. D. Oldham, Rec. 21, 150 (1888); H. H. Hayden, Mem. 36, 97 (1904).
[28] H. H. Hayden, Mem. 36, 97 (1904).
[29] R. Lydekker, Mem. 22, 267 (1883).

on the lower Para river where it is said to intrude Permian as well as Cambrian strata.[30] That a pre-Permian granite must have existed in the Spiti neighbourhood, however, is shown by the occurrence of a pebble of biotite-granite in the Permian conglomerate of that area.[31]

Chamba State and Dalhousie.—Between the towns of Dalhousie and Chamba is the broad granite tract of Dainkund, some 6½ miles across; north-westward, where it crosses the Ravi river, it contracts abruptly from one side to a very thin sill-like band not more than 250 feet wide and often less. Two or three miles west of the main intrusion and its attenuated continuation, another sill crops out, closely parallel to the boundary of the main mass.

The Dainkund granite varies from a foliated gneiss to a granite showing only traces of foliation. Sometimes there is a sharp line of division between the two extreme types, and evidence is not wanting that the granitoid variety, which is porphyritic in character, is slightly younger than the gneissic. The margin of the intrusion is in most cases the foliated rock, its foliation conforming to the Chail (Haimanta) schists into which it has intruded. In the more central portions of the *massif* the granitoid variety predominates, sometimes invading the gneissic type and occasionally even penetrating the gneissic margin and the adjoining schists.[32] Another variety found in the central parts is a fine-grained uniform granite. The contracted continuation to the northwest is a foliated gneiss, but even here it is accompanied by veins of the porphyritic granitoid rock in the adjoining schists. Inclusions of the schists, some of them splintered and fractured, have been recorded by McMahon in the porphyritic granite and are more numerous in the vicinity of the boundary of the schist outcrop; fragments in the process of being broken off from the schist margin have been noticed. The schists in contact with the granite near Dalhousie are described as having developed tourmaline, biotite, muscovite, garnet, magnetite and cryptocrystalline mica; elsewhere they are seen to be intruded by the porphyritic granite. A band of decomposed diabase was noted in the gneiss. Granitoid rocks are greatly developed in the Kund-Kaplas area. Most types of the Dainkund intrusion consist of the usual orthoclase, quartz, biotite and muscovite, the granitoid variety containing in addition, tourmaline in minute or moderately-sized crystals, and sometimes a few small garnets. Some of the felspar phenocrysts attain a length of 3½ inches. In the opinion of McMahon the Chor Granite is the same as that of Dainkund and also that of Dhaoladhar.

The westerly sill differs from the main Dainkund mass in the absence of muscovite, tourmaline and garnet; it is this band, intrusive into beds identified by West as Chails, which so closely resembles the sill seen crossing the Sutlej at Luhri further southeast.

[30] H. H. Hayden, Mem. 36, 8 (1904); this requires confirmation.

[31] H. H. Hayden, Mem. 36, 98 (1904).

[32] C. A. McMahon, Rec. 15, 44-45 (1882).

Tehri Garhwal.—A gneissose granite near the valley known as the Rama Sarai in the Tehri Himalaya, northeast of Chakrata, is described by Middlemiss as petrologically identical with the rock in the Chor mountain, containing the same quartz and felspar with sometimes a predominance of the former, the same pale and dark micas, and the same tourmaline crystals here and there, occurring abundantly in cracks and veins.[33] This granite exhibits a foliation which is almost universally horizontal or nearly so; it appears to form a sill in quartzites identified as equivalent to the Bawar quartzites of Jaunsar, which Pilgrim and West equate with the Chails of Simla, and appears to have been thrust, like the Chor and Lansdowne granites, with the intruded host rocks, over the Deoban Limestone.

British Garhwal.—The granites of the Arwa and Saraswati valleys have already been mentioned. The Lansdowne granite exposed in the isolated peak of Malogarhi (Kaladanda; 6,000 feet) is interesting in that it affords support to the view that its intrusion and the intrusion of its equivalents in other parts of the Himalaya took place before the end of the Carboniferous period. This evidence, discovered and described by Auden, lies in the orientation of its phenocrysts and of lenticular and linear structures in the rock. The range of this orientation, like that observed in the conglomerate pebbles, fold ripples and schistosity of the Jaunsar series, average in many places N.E.-S.W., a direction more or less coincident with that of the Aravalli chain and at right angles to the Himalayan axis. In the same way, idioblasts of andalusite in hornfels, the product of the neighbouring Dudatoli granite which is almost certainly of the same intrusion as the Lansdowne rock, sometimes show the same orientation. Oblique structures had long ago been noted in Kumaon by Middlemiss who records the presence of basic volcanics with interbedded quartzites and slates, showing folding, cleavage and crushing along a N.-S. strike, instead of the normal Himalayan trend which is here W.N.W.-E.S.E. It has been suggested that all these phenomena are relics of the old Aravalli folding. The validity of some of these supposed Aravalli structural relics requires extended investigation, but it cannot be expected that Aravalli orientations in every case—or even in most cases—could have survived the later and mainly Tertiary thrusting of the Himalaya which would have obliterated many former signs of Aravalli orogeny. The crux of the argument lies in the experience that no orientation along Aravalli directions has been noted in any Himalayan strata higher than the Blaini, the base of which is uppermost Carboniferous.[34] According to Auden, the Lansdowne granite, together with its country rock of Chandpur (?=Chail) phyllites, have been thrust, subsequent to intrusion, to their present position upon Nummulitic rocks.

Between the Ganges and the Ramganga, nearly 30 miles northeast of Lansdowne is the pine-covered summit of Dudatoli ("Musa-Ka-Kotha"; 10,188 feet), the source of the Ramganga and the eastern

[33] C. S. Middlemiss, Rec. 20, 29 (1887).
[34] J. B. Auden, Rec. 66, 467 (1932).

and western Nyar rivers, and by far the highest mountain in the immediate neighbourhood. In the way it rises above the surrounding country as well as in its geological structure it is reminiscent of the Chor Mountain.[35] Dudatoli and its neighbouring spurs occupy a broad N.W.-S.E. syncline, made up of mica schists of Chandpur age and a gneissose granite which has insinuated itself into the schists at various horizons in lenticular sills which expand or thin out with great rapidity. The outcrop of the granite is irregular but is bent round elliptically. In some parts of the syncline the schists predominate almost to the exclusion of the granite ; in other parts, such as the Dudatoli ridge itself, it is the granite which prevails, with only one or two thin bands of mica schist. The schists show clear signs of contact metamorphism ; away from the granite they grade into ordinary slates and quartzites, while nearer the intrusion garnets make their appearance, minute at first but gradually increasing in size up to that of a pea and occasionally even to larger crystals.

The Dudatoli rock is a coarse granite, eminently felspathic, with tourmaline, black and white micas, orthoclase usually in large porphyritic *augen* and sometimes a few garnets. All degrees of foliation are present, the rock varying from a normal unfoliated granite to a highly schistose gneiss, the latter type occurring in the immediate neighbourhood of the intruded schists. The bulk of the intrusion is slightly foliated ; the entirely unfoliated variety is usually porphyritic and is only found in the larger masses and then only in small amount. The foliation in the schists is invariably parallel to the foliation in the granite. The line of division between the two rocks is in most cases sharp but in a few examples there is a gradual mergence of one into the other. Inclusions of schist do not appear to be numerous in the granite.

The Dudatoli granite is said to resemble strongly both the Lansdowne and Rama Sarai granites. The gneissose granite around Ranikhet and Dwarahath may perhaps belong to this suite.[36]

In the main range to the north are great masses of granite, veins of which form a network in the schists of the Vaikrita system (pre-Cambrian). In the Niti area, the entire thickness of the Vaikrita schists is said to be absent, perhaps through faulting, and the granite is spoken of by Griesbach as penetrating not only the quartzites and slates of the Haimanta system (pre-Cambrian or Cambrian) but also an older granitic gneiss. This is the granite seen in great force further west, thickening out into several masses west of Shipki on the Hundes frontier.[37] It is possible that the older gneiss spoken of by Griesbach and correlated by him with the Central Gneiss, was but slightly earlier phase of the suite of intrusions represented by the newer granite just mentioned. Griesbach admits that mineralogically the one approaches closely the other, but has suggested a Tertiary age for the younger suite, as well as for the granite of the Hindu

[35] C. S. Middlemiss, Rec. 20, 135 (1887).

[36] C. S. Middlemiss, Rec. 20, 40 (1887).

[37] Mem. 23, 42-43 (1891).

Kush and Afghanistan. The so-called "newer" granite is clearly porphyritic and is described as composed of muscovite, quartz and albite with accessories, of which the commonest are tourmaline, garnet, beryl and others ; he records kyanite from both the granites, especially at Niti.

Almora.—In the Lissar valley in Almora hornblendic granite veins in the phyllites of the lowest Haimantas have altered these rocks to garnetiferous, sometimes micaceous schist, highly contorted and plicated.[38]

Sikkim.—A description of the gneiss of Sikkim and its relationships has already been given, since it is largely a hybrid rock involving the sedimentary Daling beds (see p. 318). The greater part of upper Sikkim consists of this so-called Darjeeling Gneiss, and of it some of the high peaks of this portion of the Himalaya are formed. In the cliffs of the Kangbachen and Khunza valleys, west of Kinchinjunga, as well as in the lower portion at least of the northern face of the Kinchinjunga *massif*, the gneiss has an *augen* structure, with porphyritic, sheared and rounded eyes of white orthoclase ; this feature has been noted in the massive walls of Jannu and further west in the Yangma valley and continues south-eastwards to Kabru and the Guicha La.[39] This appears to be the *augen* gneiss which Herr Dyrenfurth suggests is younger than his Mesozoic "Dadang series". According to Garwood, the northeast face of Kinchinjunga is composed of biotite gneiss and hornblende schist intruded by sills of granite or pegmatite.[40] The gneiss of northeast Sikkim has the same general N.W.-S.E. strike as that of the south, but veers westwards to a direction more or less E.-W. ; the greater number of low dips give it the appearance of being less disturbed. In the northeast of Sikkim, the low dip of the gneiss is with few exceptions uniformly to the northeast, and has been shown by Auden to be due in some places to extensive recumbent folding.[41] Along the crest of the Singalila ridge to the west, and along the Cho La range to the east, the dip is parctically horizontal, as it is also in the "wedge Peak" range northwest of Kinchinjunga, in the Jelap La in southeastern Sikkim and in the Yak La. According to Blanford, the rock of the Jelap La is a pale-coloured, highly felspathic gneiss. As already explained, Messrs. Heim and Gansser have shown that the Darjeeling Gneiss of Sikkim composes the core of a gigantic overfolded and recumbent anticline.

Intrusions of a later granite occur in the north. Auden reports that thin veins of aplite begin to be noticeable in the gneisses at Tong and become conspicuous at Chungtang. "On the northern slopes of Chomiomo, around the Sebo La and on the precipices north and west of the upper Sebo Chu valley the gneisses become riddled with bosses, thick dykes and sills of a fine-grained white granite", cutting across the folds of the gneiss and therefore younger than the

[38] C. L. Griesbach, Mem. 23, 45 (1891).
[39] E. J. Garwood & D. Freshfield, "Round Kangchenjunga", 292 (1903).
[40] E. J. Garwood & D. Freshfield, "Round Kangchenjunga", 286 (1903).
[41] Rec. 69, 149 (1935).

folding. In most cases the intrusion is clearly discordant, but in some cases it is of a *lit-par-lit* character. This younger granite is composed of biotite, muscovite, oligoclase and quartz, with tourmaline, pink topaz, rutile and occasionally sillimanite as accessories.[42] Hayden found beryl in the pegmatites of the Lachen valley. This unfoliated granite of Sikkim is regarded by Hayden as the equivalent of a similar granite in the Chumbi valley, which intrudes Jurassic beds and is probably of Tertiary age. It is described as associated with and probably genetically related to the granite of the Kyi Chu valley. which occurs on the opposite bank of the Tsangpo and extends thence in a broad band along the valley of the Kyi Chu up to and beyond Lhasa. This rock is said to differ markedly from both the typically foliated biotite granite and the muscovite-tourmaline granite of the Himalayan crystalline zone.[43]

A massive coarse gneiss, with veins and lenticles of granitic rock. with or without crystals of hornblende and in places highly schorlaceous, is seen at the Guicha La and elsewhere, and very probably forms the peak of Pandim (22,020 feet).

Nepal.—The outcrop of the Darjeeling Gneiss, as well as that of the Dalings, continues westwards from Sikkim into Nepal. In the Kathmandu traverse, a porphyritic muscovite granite occurs near Kulikhani, carrying tourmaline, muscovite, biotite in smaller quantity, orthoclase with microperthite, and albite.[44] It is the source of the aplite veins which occasionally seam the metamorphosed and mainly arenaceous rocks to the south which form part of the Daling series; northwards it is succeeded by granulites, schists, phyllites and calcareous rocks, corresponding probably to the upper portion of the same series. In its position and relationships it resembles the granites of Lansdowne, Dudatoli, Chor, etc., though differing somewhat in mineral composition. Gneissic granite and tourmaline pegmatite are found on the north side of the Nepal valley, northwest of Kathmandu; these intrusions contain abundant inclusions of biotite-schist, tuff, hornblende-schist, and occasionally quartzite. A little further north, the Darjeeling Gneiss, which here consists of a muscovite-gneiss with tourmaline, calc granulites, quartz-biotite granutities and biotite-schists, has been mapped by Auden, forming the syncline of Sheopuri Lekh in the Daling beds; its outcrop terminates eastwards two or three miles west of the Indrawati.

The Darjeeling Gneiss, similar to that found in the Sheopuri Lekh has been again recognised further east above Udaipur Garhi. It appears to be thrust over rocks resembling the Krol.[45]

Further east, a large tongue-shaped outcrop of the hybrid Darjeeling Gneiss projects southwards between the Arun and the Tamur to a point a little beyond Dhankuta. Flanked on both sides by more or less unmixed Daling beds it is continuous north-eastwards with the

[42] J. B. Auden, Rec. 69, 150 (1935).
[43] H. H. Hayden, Mem. 36, 180 (1907).
[44] J. B. Auden, Rec. 69, 140 (1935).
[45] J. B. Auden. Rec. 69, 143 (1935).

extensive and heterogeneous tract of the Gneiss which includes the peak of Kinchinjunga and the town of Lachen. In a dip-slope from the Angbung ridge northwards, Auden has found within the Daling beds a thick sill of tourmaline-bearing muscovite granite, which is highly sheared and mylonised and must, therefore, represent an intrusion prior to the earliest of the Tertiary thrust movements.

Everest area.—The Everest area has already been described (p. 1419). Wager's Pelitic series and the intimate injections therein of biotite gneiss are almost certainly the equivalent of the upper part of the Daling beds and their gneissic intrusions, and correspond, therefore, to the Darjeeling Gneiss.[46] The granitic element in this gneiss may be the equivalent of the Central Gneiss. In the Everest area this gneissic complex is further injected with dykes and sills of all sizes of a younger tourmaline-muscovite granite or pegmatite, the latter being often present to such an extent as to be the predominant rock.[47] This granite not only penetrates the older composite gneiss but also the Tibetan Jurassics; it is the youngest of the igneous rocks in the area, and both Heron and Wager agree that it is probably Tertiary. In texture it varies from a fine, homogeneous granite to a coarse porphyritic pegmatite sometimes with graphic intergrowths of quartz and felspar. It is an almost horizontal sill of the granite which, between the heights of 27,000 and 27,600 feet stretches throughout the mountain, and by its superior hardness gives rise to the prominent shoulder northeast of the main peak.

The valleys on the northeastern and eastern sides of Everest are occupied by the Darjeeling Gneiss. The base of Makalu is said to be composed of the same hybrid rock, while its upper portion consists of a pale granite which may be the Tertiary granite seen around Everest.

Bhutan and southeastern Tibet (Tsang and U).—A granite intrusion extends from the western boundary of Bhutan through the mountain of Chomo Lhari towards the northeast, forming the range of snowy peaks which constitute the water-parting between the drainage flowing north to the Tsangpo and the Yamdrok Tso and the southwardly flowing rivers of the Bhutan highlands. Offshoots from this granite stretch northwards to the heights north of the Karo La, the only group of snowy peaks between north Bhutan and the Tsangpo. A small mass of the granite is found in the valley of the Nyang Chu some 16 miles south of Gyantse. These smaller intrusive masses are not superficially connected with the Central gneiss of the Himalaya but. according to Hayden, their close genetic relationship to it renders it probable that they are offshoots from the same magma, ramifying along channels of weakness in the folded sedimentary beds. "The more intricate the ramification, the more complicated will be the structural conditions and consequently the orography, and it would seem, therefore, that the change from the comparative simplicity of the northern range of the Himalaya in

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[46] H. Ruttledge, Everest, 325 (1933).
[47] A. M. Heron, Rec. 54, 220 (1922).

their central portion to the complexity in the eastern, is due largely to the extensive intrusions of granite along lines of weakness, and that the further we go to the east, the more complex will the conditions become ".[48]

A granite differing from the typical Himalayan granite ("Central Gneiss") in containing large quantities of hornblende and sphene is seen in the valley of the Tsangpo between Shigarse and Chaksam, and also throughout the valley of the Kyi Chu up to Lhasa.[49] This granite forms a wide belt following the valleys of those two rivers. The selection of this rock instead of the Jurassic slates and quartzites by these two rivers, is considered to be one of the effects of the wide diurnal range of temperature which has a more powerful disintegrating action on a coarse heterogeneous rock like the Kyi Chu granite than on the softer but more compact and homogeneous slates. At Chaksam ferry, a large hill mass on the right bank of the river is composed of a rock approaching syenite but undoubtedly related to the granite on the opposite bank of the river, differing only in the larger proportion of plagioclase and ferromagnesian silicates it contains.

The ancient rocks of the Chumbi valley have already been mentioned (p. 325), including the Darjeeling Gneiss. The granite around Gautsa is believed by Wager to be of Tertiary age. Throughout the Ammo Chu the rock is a coarse granite.

Aka Hills.—From the number of boulders of gneiss brought down by the rivers of the Aka Hills, this rock must occur *in situ* not very much further north.

Dafla Hills.—The peaks of Misa Parbat and Shengorh in the Dafla Hills are composed of granite with large felspar crystals. This granite is described as passing through hornblendic gneiss into mica-schists and quartzites thought to belong to the Daling Series.[50]

Miri Hills.—Strongly foliated gneiss is represented in the pebbles found in the Subansiri gorge of the Miri Hills ; granite pebbles are rare.[51]

Miju Ranges.—The rocks for twenty-five miles E. N. E. of Brahmaund in the Miju country are said to be metamorphic rocks intruded in places by granite[52] ; the latter rock is seen at the So stream. Judging from the debris in the Kamlang Pani, there is reason to believe that the higher parts of the Dapha Bum range, culminating in the peak of Dapha Bum (Mathaidong ; 15,010 feet), are composed of gneiss and granite, and that an axial core of these rocks extends for a considerable distance to the northwest along the flank of the metamorphics. Of the granite and gneiss in the hills of the Bor Kamti country, nothing is definitely known, but from their greater

[48] H. H. Hayden, Mem. 36, 127 (1907).
[49] H. H. Hayden, Rec. 32, 168 (1905).
[50] H. H. Godwin-Austen, J. A. S. B., 44, pt. 2, 39 (1875).
[51] J. M. Maclaren, Rec. 31, 185 (1904).
[52] R. Wilcox, As. Res., 17, 370-386 (1832).

resistance to weathering it is inferred that they form the higher ranges of 11,000 to 14,000 feet.

Singpho Hills.—Two very large masses of a strongly foliated hornblendic gneiss, some of it garnetiferous, have been observed by La Touche about seven miles below Kumki, in the Upper Dihing basin, but it is not certain that they are *in situ*.[53]

Kashmir.—[54]Across the Kashmir border in the district of Rupshu, a small outcrop of gneiss extends from the western shore of the Tso Moriri (Tsho Morari) up among the Permian and Carboniferous beds of this region.[55] It was at first taken for a highly metamorphosed representative of the Lower Silurian quartzite of Spiti, but its chemical composition is that of a true granite and, as Hayden suggests, it is probably the remains of a crushed-out granite laccolith. It is an *augen* gneiss with large eyes of felspar ; the bulk of the rock consists of quartz, felspar—chiefly orthoclase and microcline with a little plagioclase—and a pale, often colourless biotite, with rods of tourmaline along the foliation planes. Associated with it are bands of a quartz-felspar-muscovite rock with no biotite, a considerable amount of plagioclase and some tourmaline. Interbanded with the *augen* gneiss are what are believed to be some metamorphosed sediments in the form of biotite schist, some of it with considerable quantities of zoisite and calcite. Running through this gneiss, in bands usually parallel to but occasionally crossing its foliation, is another quartz-felspar-biotite rock, foliated and gneissose but containing biotite in irregular blotches and not in layers ; this rock, probably a later phase of the intrusion, is again seen some forty miles to the southwest at Oocti, also among Carboniferous and Permian beds. A rock similar to the *augen* gneiss of Tso Moriri is found in the Chandra valley between Spiti and Kulu. The common granite of Rupshu is very similar to and is an offshoot from the Principal granite of the Sutlej and the Candra valley—a biotite granite with few accessories—but differs slightly in containing a considerable amount of blue quartz. It can in fact be traced from the Sutlej to the range bordering the eastern side of the Para river, above Akse and Kharak in western Tibet.

In the Zanskar range the crystallines mapped include the Central Gneiss which, for instance, is said to be visible in the Bhaga valley. On the south flank of the range, about 120 miles southeast of the Burzil Pass, are the sapphire mines of Padar. According to Middlemiss, the sapphires occur in lenticles of kaolinised pegmatite, enclosed in or intrusive into, very much larger lenses of actinolite-tremolite rock ; the latter is probably a local modification of associated crystalline limestone which occurs interbedded with biotite-granite

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[53] Rec. 19, 113 (1886).

[54] The delimitation of the two larger tracts of Crystalline rocks in Kashmir depicted on the 32-mile map requires drastic revision. These tracts include not only a gneissose granite corresponding probably to the "Central Gneiss", but also a series of schists penetrated by the granite and found therein as inclusions.

[55] H. H. Hayden, Mem. 36, 94-96 (1904).

and hornblende and garnetiferous gneisses; the invaded rocks have been identified by Wadia as members of the Salkhala series.[56] The pegmatite is a coarse-grained aggregate of large milk-white felspars, much quartz, and scattered plates of dark mica up to an inch or so in diameter; as accessories this rock contains in addition to the sapphires, tourmaline, mostly black and sometimes 4-5 inches in length, light green euclase, kyanite, minute red garnets, cookeite enveloping green and brown tourmaline, amblygonite, prehnite, copper carbonate, beryl, lazulite, hambergite and rock crystal.[57]

Much of Baltistan consists of gneiss and granite. The granodiorite, probably of Tertiary age, seen along the Dras river, thirty miles below Dras, has already been mentioned. This rock at the confluence of the Dras and Shingo rivers is a hornblende granite, of both banded and non-banded varieties, and full of basic inclusions probably of the Dras volcanics (Cretaceous-Eocene); the strike of the bands is N.N.W.-S.S.E. A somewhat more basic type is seen near Chunagund.[58] This granite is in all probability identical with that found elsewhere by Wadia intruding Eocene limestones. Traced north-westwards the granite is seen to the southwest of Skardu and throughout the Deosai plains, forming a highly indented boundary with the volcanic suit[59], and full of the basic inclusions of epidiorite or hornblende granulite derived from original dolerite and basalt; these inclusions increase in number and size until along the bank of the Indus, Auden found them to be several yards in length. In addition the rock carries occasional inclusions of slate and quartzite, showing slight marginal metamorphism. Near the Kalapani Rest House on the Astor-Gilgit road this granite is seen sending out veins and apophyses through the bedding planes of the tuffs and into the ashes and lava flows of the Dras Volcanic series; with the rocks of this series the granite has been found by Wadia forming fine-grained, porphyritic hybrids of vivid colours.[60] That the intrusion of the granite was subsequent to the folding of the Cretaceous is inferred by Wadia from the fact that the granite takes no part in the tectonic deformation of the country but remains almost entirely massive and unfoliated.

On the other side of the river at Tarkuti the same granite is seen sending tongues into the slates, and further north intrusive sills into schists, gneisses, marbles and basic rocks. This hornblende granite also crops out along the Indus valley near its union with the Shyok.

At the confluence of the Indus and Shyok is a biotite granite without hornblende, traversed by a network of basic dykes and sills. The latter show metamorphism which, Auden suggests, may have been caused, not by the biotite granite which has every appearance of being the host rock, but by neighbouring hornblende granite. If this

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[56] Gen. Rep. Rec. 67, 41 (1933).
[57] F. R. Mallet, Rec. 32, 228-229 (1905); R. C. Burton, Rec. 43 168-172 (1913).
[58] J. B. Auden, Rec. 69, 125 (1935).
[59] D. N. Wadia, Rec. 72, 158 (1937).
[60] Rec. 68, 420-421 (1934).

is not the case the biotite granite may be a variant of the hornblende granite which always contains a certain amount of biotite in addition to hornblende ; more probably the biotite granite belongs to an older intrusion altogether. The younger granites continue past Shigar to Tungmo, intrusive into basic rocks, mica schists, and the biotite gneiss of the aquamarine mines area. The aquamarine mines of Daso (Dusso), a village below Ganchen peak, lie in the Braldu valley a few miles above its junction with the Shigar, in the Skardu *tahsil*. The prevailing formation here and for many miles around is a massive biotite gneiss, interrupted at intervals by extensive veins of irregularly disributed coarse pegmatite which is the matrix of the aquamarine.[61] The gneiss possesses a distinct foliation which is often wavy and puckered ; the different layers vary in coarseness of grain and the proportion of component minerals, the pale layers expanding sometimes to considerable thicknesses. The primary minerals of the pegmatite are quartz and orthoclase with some albite ; next in order of frequency come black tourmaline and muscovite, the former ranging up to 4 inches long, and then beryl and a little deep coloured garnet.

East of the Biafo glacier, the main Karakoram range with its more massive peaks is probably composed of hornblende and biotite-granite, judging from the moraine matter brought down therefrom.[62] The northern slope of the peak K_2 (Mount Godwin-Austen) is composed mainly of *augen* gneiss. The Punmah basin is excavated mostly in gneisses and granites.[63] The granite which builds the core of the Ladakh range and is found in the Karakoram area is regarded by De Terra as an intrusion of late Palæozoic age ; [64] if however, as Auden believes, this granite belongs to the same suite as the granodiorite below Dras, which contains xenoliths of the Dras volcanic series, it is in all probability of post-Cretaceous age. The great line of peaks between the Biafo and the Choktoi branch of the Nobande Sobande glacier is built of granite ; granite is also extensively found on the other side of the Karakoram along the southwest side of the Shaksgam valley as well as in the Aghil range east of the Aghil Pass.[65]

The area around Nanga Parbat (26,620 feet) has been well described by Wadia.[66] The prevalent rock in the higher portion of this precipitous mountain is a pale-coloured, thinly-foliated, felspathic, biotite granite, strongly resembling the Central Granite or gneiss of Dalhousie and Hazara. In it quartz is abundant, muscovite is not common, while the plagioclase is usually microcline ; the less foliated types are porphyritic and the foliated varieties characterised by *augen*. The main mass of the mountain and its group of satellite peaks, however, are built up almost entirely of a thinly-foliated, highly contorted, streaky,

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[61] C. S. Middlemiss & L. J. Prashad. Rec. 49, 163 (1918).

[62] J. B. Auden, Rec. 69, 128 (1935).

[63] A. Desio Geogr. Journ. 75, 403 (1930).

[64] Geol. Forsch. im Westl. K'un-lun und Karakorum-Himalaya, 113 (1932).

[65] J. B. Auden, Private Communication.

[66] Rec. 66, 212-234 (1932)

biotite-gneiss, which is believed to be a paragneiss, a result of the extreme metamorphism of the Salkhala sediments by the granite intrusion. This para-gneiss includes subordinate bands of coarsely recrystallised marble, calciphyre, calcareous schist, banded granulite, garnetiferous mica-schist, garnetiferous graphite-schist and garnetiferous actinolite-schist. The whole finely and uniformly laminated succession shows a persistent regional dip towards the northwest, a somewhat unexpected feature since it associates Nanga Parbat with the Hazara side of the syntaxis rather than with the Himalayan ; it is extensively traversed by basic intrusions, belonging perhaps to the Panjal Trap, and by acid intrusions including the normal biotite granite of the higher altitudes and a finer grained hornblende granite; the latter, which occurs elsewhere and will be considered further, is either a late phase of the Central intrusion or the post-Cretaceous granite found to the southeast.

Around the mass of Salkhala paragneiss and granite intrusions is a zone in which the Salkhalas have been so intimately intruded by the granite as to form a hybrid complex of the sedimentary and igneous rocks in varying proportions. This zone reaches northwards to Bunji and is again seen with the Central granitic gneiss further still to the north along the lower section of the Gilgit valley.

Further south a ring of granite intrusions surrounds the Palæozoic basin, the principal being the lofty Kazi Nag *massif* to the southwest, overlooking the Jhelum gorge above Uri, the Jagran boss on the west, several large and small outcrops on the north side of the Kishenganga, and the Hant *massif* on the south, a few miles north of the Wular Lake. With the exception of the Hant granite the rock is the ordinary foliated biotite gneiss of the normal Central Gneiss type. The largest batholiths of this are seen on the Kishenganga slopes of the Great Himalaya protruding through the Salkhala rocks, but minor intrusions and apophyses have penetrated the Dogra Slates and, in two or three cases, beds with Cambrian fossils. The Jagran boss surrounded mostly by Slates comes into contact with Cambrian beds near Keran and sends out therein long narrow sharply defined veins and sills.[67] The Kazi Nag intrusion has, according to Wadia, pierced the Dogra Slates and Salkhala rocks, metamorphosing the former to phyllites and chlorite schists. The Kazi Nag is described as very similar in character to the Chor Granite.

On the southeast side of the basin, to the north of Srinagar, the granite noted by Middlemiss in the Sind valley, near Margund, is not very gneissose and apparently a laccolith ; the contact sedimentaries are well metamorphosed mica schists and quartz schists, mapped by Wadia as Lower Cambrian.[68] De Terra concludes that this is a middle or upper carboniferous intrusion.[69] He remarks that the outlier of granite between Kargil and the Indus should be of the same age.

[67] D. N. Wadia, Rec. 68, 136 (1934).
[68] Rec. 41, 139 (1911).
[69] Mem. Connect. Acad. 8, 57-58, (1935).

In some cases the biotite granite of Central Kashmir has a massive habit but in the majority of cases it tends to ramify among the country rocks, taking full advantage of the fissility of the slates to form frequently a composite hybrid rock like that seen in the zone surrounding Nanga Parbat. Such intimate intermixture is seen especially on the northern slopes of Kazi Nag and in the Salkhalas of the Kishenganga valley, occupying an aureole of profusely injected and thermally metamorphosed slates; in the latter around Kazi Nag numerous secondary minerals have been developed.[70]

Some of the granite, especially that which penetrates the Panjal Trap is hornblendic and differs in several respects from the normal biotitic rock. The smooth iceplaned dome of the Hant-*massif* is the best example and consists of a massive medium-grained granite in which most of the biotite seems to have been replaced by hornblende. It has the shape of a laccolith surrounded largely by Cambrian beds and laid bare by the erosion and removal of superjacent slates; from it bedded sills pass into the lower Cambrian sediments, but to the north it invades the Panjal Trap. According to Wadia it is younger than the biotite rock, and this agrees with evidence elsewhere.

In Punch bosses, apophyses and veins of felspathic granitoid gneiss are seen intrusive along the cleavage planes of the Dogra Slates or the bedding planes of the Tanawals (? Devonian), forming narrow elongated bands.[71] Both in structure and composition this gneiss, according to Wadia, shows relations with the Central Gneiss of Chamba, Dalhousie and the Chenab valley, to the southeast, and with that of Hazara to the northwest. Such granite is represented by very small intrusive masses on the south side of the Baramula gorge towards Gulmarg.[72] The largest of the outcrops, the Kopra boss, lies further south, in a line with the Kazi Nag intrusion. About seven miles long by one mile in maximum breadth, it extends in a N. N. W.-S. S. E. direction, lying mainly in the Dogra Slate zone but impinging intrusively on the large Tanawal outcrop of the Kacharban valley. Its contact effect on the argillaceous country rocks is the production of fine, wavy, silky schists, not very well defined from the rim of the gneiss; the contact metamorphism along such junctions, however, is surprisingly small, at times scarcely more than a discoloration of the slates, the greatest change being the production of secondary chlorite. The central part of the intrusion is coarsely granitoid with felspars over two inches long, but towards the periphery the rock becomes a thinly-foliated, fine-grained, schistose gneiss with *augen* structure. The granitoid portion, with a specific gravity of 2·63-2·65, contains more than 70 per cent. of felspar consisting of orthoclase with some albite. Mica, except in the foliated types, is scanty, especially muscovite; most of the biotite has been replaced by chlorite. Along its margin a few grains of tourmaline, grossularite and cordierite are observable. Numerous apophyses and

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[70] D. N. Wadia. Rec. 68, 169 (1934).
[71] D. N. Wadia. Mem. 51, 219 & 223 (1928).
[72] Gen. Rep. Rec. 44, 37 (1914).

veins of finer granitic material have found their way into the surrounding Slates or Tanawals, the finest intrusions attaining almost a *lit-par-lit* grade of texture.[73] Related to the gneiss are some sills of felsitic rhyolite and porphyry, and some quartz veins.

The granite pebbles found in the Agglomeratic Slates and in the Kuling conglomerate (uppermost Carboniferous or Lower Permian) were probably derived from the Central Gneiss granite. The bands of gneiss or gneissose granite seen by Middlemiss penetrating the Panjal slates below the Golabgarh pass belong to a later intrusion.[74]

North-West Frontier.—West of the Nanga Parbat region, in Kagan, the northern part of the Hazara district, between Narang and the Babusar Pass into the Chilas region of the Indus valley the rocks comprise a finely stratified sequence of alternating layers of gneiss, graphitic schists, mica schists, garnetiferous schists and marble. Contact metamorphism accompanied by pneumatolytic and hydrothermal processes, resulting from the close intrusive association of gneiss with a sedimentary series containing so much limestone and carbon, has caused the development of a large number of secondary minerals, among which the following have been identified: quartz, felspar, phlogopite, actinolite, tremolite, epidote, sphene, pyrite, pyrrhotite, zoisite, fluorite, forsterite, chalcopyrite, graphite, grossularite, almandite, pyrope, idocrase, talc, tourmaline, beryl, corundum and others.[75] Elsewhere in Kagan, intrusions of the Central Gneiss, often in the form of a porphyritic granitoid rock with tourmaline and garnet as rather infrequent accessories, are seen protruding through the Salkhalas and Dogra Slates.

Further south in the same district, the same gneissose granite is equated by Middlemiss with the Central Gneiss and described as the equivalent of the Chor granite in the Simla area, the Kaladanda granite of Lansdowne, the Dudatoli granite, the Kashmir granite, and the gneissose granite of Dalhousie and Chamba.[76] Bands of the granite are seen intruding the schists and slates of the older rocks, sometimes cutting across but more generally parallel to the foliation of the latter; the thickness of the bands varies greatly from an inch or so to four or five miles. The Infra-Trias and the Tanawals it is claimed, are not penetrated by the granite. In places the permeation of the schists by the granite has taken place on a minute scale.

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[73] In a recent note, Mr. Wadia records that two varieties of granite have been injected in the Salkhala and Dogra Slate zone of the Pir Panjal: (1) the usual type of richly felspathic, porphyritic biotite-gneiss with much free quartz (Central Gneiss); (ii) a less acid, darker biotite-granite with glassy plagioclase and conspicuous sphene. He remarks that their relative ages are not certain, but states that the latter granite is more centrally situated in the bosses, while the former constitutes apophysal parts. West of Golabgarh the apophysal granite comes in contact with and penetrates the Agglomeratic Slates. (Gen. Rep. Rec. 72, 76 (1937).

[74] Rec. 37, 288-89 (1908).

[75] D. N. Wadia, Rec. 65, 199-200 (1931).

[76] Mem. 26, 61-62 (1896).

The rock consists of a granular aggregate of quartz, felspar and white and black mica, with accessory tourmaline, magnetite, apatite and plagioclase. In places, especially near the margins of the bands and rock masses, large porphyritic crystals of orthoclase are to be seen, averaging 3-4 inches in length but varying from 2 to 8 inches, the larger ones often exhibiting a very vague outline ; they generally show included magnetite and apatite. In some of the finer-grained aplite apophyses occurring among the schistose rocks the minute and broken crystals of tourmaline give the rock a banded appearance. Another feature, which is extremely prominent near Mansehra (Mansahra ; Mansahrah), is the frequency and number of included fragments of schist and quartzite ; some of these are only three or four inches long but other larger inclusions, more rounded in appearance, range up to about a foot across. These inclusions are sometimes so crowded as to give the appearance of an agglomerate. The aplite apophyses differ in being finer in grain, usually slightly more felspathic, and in containing a greater amount of tourmaline, no black mica and but little white mica. Pegmatite veins are seen in the ordinary gneissose granite of the Black Mountain.

There are all gradations of the gneissose granite from non-foliated to foliated. In the non-foliated type the porphyritic felspars are orientated in all directions and somewhat blurred in outline. In the foliated types both the porphyritic and the smaller granules of felspar are sometimes drawn out into *augen* ; in the more extreme cases the *augen* overlap each other.

Basic trap dykes are seen intruding both the schists and the gneissose granite. If these belong to the Panjal Trap suite, as they may well do, we have evidence that the bulk at least of the granite or gneiss in Hazara is not later than Carboniferous.

The Hindu Kush from east of the Shiba Pass to the Little Pamir, with all the mountainous country to the south of it, including Kaffiristan, Chitral. Dardistan, Swat and Dir as well as Gilgit and north-western Kashmir, is formed chiefly of old crystalline rocks which are a western prolongation of the Great Himalayan belt.[77] The greater part of the Hindu Kush range is composed of what has been described as syenitic granite, intrusive into Cretaceous strata and, according to Griesbach, probably of Tertiary age ; it is apparently of the same lithological character, and belongs to the same mass of intrusion as, the granite of the northern Ak Robat Kotal (south of Saighan). The granites in Dir, Swat and Chitral, including those in the Hindu Kush, have already been referred to[78] and the little that is known of them is scarcely worth repeating. Whether the Central Gneiss is represented among them remains for future work to decide. The granite of Tirich Mir in Chitral is, according to Tipper, definitely later than the Fusulina shales, quartzites and limestones of the neighbourhood ; the latter are cut out by the intrusion, the granite coming in contact with and altering the Sarikol Shales.

[77] C. S. Middlemiss, Mem. 26. 283 (1896).

[78] Pascoe, Manual of Geology of India & Burma. Vol. 1. 313.

In the Tirich valley the granite is a biotitic variety containing large phenocrysts of felspar up to four inches in length and half an inch across. Along the strike southwards the rock becomes first a regular *augen* gneiss and ultimately a fine-grained foliated gneiss.[79] Large masses of granite intrude the garnetiferous and chiastolite schists forming the high ground between Chitral and Afghanistan; the schists are said to be of Mesozoic—probably Jurassic age. Generally the granite is fine in grain; in one of the coarser intrusions beryls, some of them of good colour and quality, have been noted by Tipper.[80]

The granite of Mirkanni at the foot of the Laorai Pass in Chitral is of unknown age and extends into Afghan territory.

A foliated soda-granite, cutting across the foliation of schists and phyllites of probably older Palæozoic age and exposed in a ridge in the Mullagori country of the Khyber Agency, has been described by Coulson. Another range, composed of soda-porphyry is seen about 46 miles to the east, in the district of Peshawar, and other outcrops of a similar rock are seen still further to the east. Coulson deduces a genetic relationship between all these occurrences. The Mullagori rock is a biotite-aegirine-arfvedsonite gneiss, the aegirine and arfvedsonite being intergrown. The porphyries differ markedly in colour and texture. A coarse-grained, gneissic type contains orthoclase-perthite and microcline-perthite, quartz and biotite, in a fine-grained siliceous groundmass. Another light-coloured felspar porphyry contains in addition to biotite, minute prisms of what appears to be aegirine, minute crystals of arivedsonite, sphene and iron ore. Other types are slightly more acid or are more porphyritic. Coulson suggests a Mesozoic age for these intrusions.[81]

Baluchistan.—In the Makran region of Baluchistan Vredenburg records small intrusions of a granite into Tertiary slates in which the effects of contact metamorphism can be seen added to those of regional metamorphism. The slates are greatly indurated, and along the junction white mica, biotite and garnet are amongst the most conspicuous minerals developed by the contact. This granite, which builds many prominent peaks, is accompanied by dykes of quartz porphyry and quartz felsite; in the plains it has weathered to typical tors.[82]

Recapitulation.—From the unclassified welter of information and suggestion available, one fact seems to emerge. It is that there are two principal granite intrusions in the Extra-peninsular region of the north. One of these appears to have taken place during some period —perhaps the Carboniferous—of the Palæozoic. This may have been the granite that invaded the ancient schists on such an intimate scale at both ends of the Himalaya, but this requires confirmation,

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[79] Gen. Rep. Rec. 54, 57 (1922).
[80] Gen. Rep. Rec. 55 13, 39 (1923).
[81] Proc. Nat. Inst. Sci. Ind., 2, 103-111 (1936).
[82] E. Vredenburg, Mem. 31, 268 (1901).

and we know that at least one earlier granite is represented in the Himalayan rock sequence. The other main granite is probably of Tertiary age and is exposed more especially in the Great Himalaya and on the Tibetan side thereof. It is especially distinguished by the presence of accessories such as tourmaline and beryl and is less liable to be foliated than the earlier intrusion. Such general statements, however, must be received with the greatest caution, and much work remains to be done on these acid intrusions of the Himalaya and its continuations.

II. BURMA.

In Burma our knowledge of acid intrusions is just as vague and inconclusive as it is of the corresponding rocks in India. Some of the granites of Burma, such as the Kabaing Granite, have already been mentioned in connection with the rocks they penetrate. One of the best known intrusions in north Burma is one found extensively exposed in the Northern Shan States.

The Tawng-Peng Granite.—In places among the Chaung Magyi rocks of the Northern Shan States are found great intrusions of a granite, which has been called by La Touche the Tawng-Peng Granite since an outcrop of the rock occupies the greater part of the State of Tawng-Peng. So far the only rocks proved to have been intruded by this magma, even in the country north of the Bawdwin lead and silver mines and west of Moho Chang, are the Chaung Magyis. Large dykes of the granite extend from the main massif towards the northeast to within five miles of the rhyolitic area of Bawdwin, and it seems quite possible that the granite may occur below the rhyolites and associated sedimentaries. Coggin Brown's conclusion is that, although the rhyolites are probably older than and genetically unconnected with, the Tawng-Peng Granite, their mineralisation in the form of the Bawdwin ores may well have been a result of the granite intrusion.[83] These ores may thus have been deposited from gases and solutions derived from the granite magma and representing the end products of the intrusion.

The outcrop in Tawng-Peng covers a large expanse of country, sweeping north-eastwards through the hills west of Bawdwin and building up the high country around Loi Mong Mong; it has been traced in this direction to the vicinity of the Loi Lem ridge, and as far as the Chinese frontier. Some insignificant occurrences have been located among the Chaung Magyi rocks on the north side of Loi Pan, in Mong Tung State, and along the southern slopes of Loi Ling in South Hsenwi,[84] extending eastwards as far as the Loi Lun range.

The Tawng-Peng Granite is typically a coarse rock, frequently with large felsper phenocrysts, and always decomposed to a considerable depth.[85] It is an ordinary white granite composed of quartz

[83] Rec. 48, 174 (1917).
[84] T. H. D. La Touche. Mem. 39, pt. 2, 59 (1913).
[85] Gen. Rep. Rec. 47, 33 (1916).

orthoclase, sometimes microcline, and biotite, with sporadic tourmaline, and usually bears evidence of intense crushing and much faulting. These faults, which in some places are filled with quartz, are in all probability much younger than the mineralised fissures in the neighbouring rhyolites and tuffs; whether they date further back than the movement which was responsible for the upheaval of the Himalaya is not clear. The Tawng-Peng Granite is, thus, a simple biotitic variety with orthoclase in excess of plagioclase, and in some places tourmaline-bearing. In certain localities it is remarkably sericitised, the sericitised rock in many cases being associated with intrusions of basalt[86]. Basic intrusions are, however, not restricted to the sericitised portions of the granite but occur rarely, and chiefly in the form of olivine-gabbro in the more normal rock[87]. In the metamorphic aureole bordering the granite, the Chaung Magyi sediments have been converted into hard quartzites, sometimes felspathic, and micaceous slates and phyllites. Iron pyrites in considerable quantity has been found in several quartz veins traversing the Chaung Magyi slates of the Tawng-Peng State[88].

Intruded along or close to the junction of the Mogok gneisses and granulites with the Mong Long Schists are several strong dykes of a coarsely crystalline granite, which is composed mainly of orthoclase with some interstitial quartz, a considerable amount of tourmaline, and accessories in the form of fibrolite, apatite and garnet[89]. It has already been mentioned in the chapter on the Archaean (p. 335), but whether it is related to the Kabaing Granite and whether it or the Kabaing Granite is of Archaean age, is doubtful. It was at first regarded as confined to the gneissic complex of Mogok but, according to Clegg, veins of it penetrate the mica schists of Mong Long as well, in which case the intrusion may be post-Purana. Whether it is of the same age as the almost tourmaline-free boss granite of Tawng-Peng is uncertain. From this granite probably come the gem tourmalines of Mong Long, found in gravelly detritus of the Nam Pai.[90] The tourmaline from the mines of Maingnin in Möng Mit (Momeit) may have a similar origin, but the veins are here concealed by alluvium.[91]

In the more easterly outcrops M. R. Sahni finds that the Tawng-Peng granite varies from a very coarse to a very fine textured rock, and in several localities contains pyrite as an original constituent; associated with it is a muscovite-granite and quartz-felspar porphyry. The Tawn-Peng Granite of these parts is intruded by dolerites and epidiorites.[92]

A gneiss found in the neighbourhood of Möng Hka is regarded by Sondhi as a hybrid formed by the soaking of mica schists by a gra-

[86] Gen. Rep. Rec. 63, 92-93 (1930).
[87] Gen. Rep. Rec. 47, 33 (1916).
[88] J. Coggin Brown, Rec. 56, 83 (1924).
[89] T. H. D. La Touche, Mem. 39, pt. 2, 47, 372 (1913).
[90] J. Coggin Brown. Rec. 56, 83 (1924).
[91] E. C. S. George, Rec. 36, 236 (1907).
[92] Gen. Rep. Rec. 65, 8 (1931); Gen. Rep. Rec. 68, 58 (1934).

nitic magma, which at the same time dissolved the greater part of the limestone bands and left only isolated bluffs of undissolved marble. For about ten miles north of Möng Hka the rocks consist entirely of these gneisses and bluffs of marble. Near Nya Wa small patches of granite are observable intruding phyllites and shales.[93]

Bawdwin Mineralisation.—The rhyolites and rhyolitic tuffs of Bawdwin, which have already been described (p. 589), have been intensely crushed and shattered along a zone coinciding with a great overthrust, which passes through Bawdwin and gives off a branch there. This zone of dislocation, which extends almost due N.-S. at Bawdwin and has been traced for many miles to the south parallel to the Nam Tu river, was taken advantage of by mineralising solutions. The age of this great Bawdwin overthrust, which is mainly responsible for the shattering of the rocks in the vicinity of the ore-body, is the same as that of the Lilu overthrust with which it is connected to the south. The latter does not appear to dislocate beds younger than the Silurian, but the question requires further investigation.[94] A minor line of thrust branches off from the main dislocation at Bawdwin and takes a more southerly course; it is at Bawdwin, therefore, that dislocation and crushing must have reached a maximum. In addition to the great faults which are responsible for the formation of the ore channel, there are others, later in age than the ore-bodies, which they sometimes displace.

Bawdwin itself was for several hundreds of years the scene of extensive mining operations on the part of the Chinese,[95] who extracted large quantities of silver from the silver-lead ores found among the tuffs and rhyolites, but threw away the bulk of the lead in the form of slag; they abandoned the area in 1868 as a result of the great Moslem rebellion in Yunnan.[96]

The lead contents of the enormous heaps of slag left by the Chinese have been recovered by modern enterprise, while exploration below the level of their underground workings revealed one of the major lead-zinc-silver ore-bodies of the world. The ore channel is at least 8,000 feet long and from 400 to 500 feet wide. The ore-body it originally contained has been separated into three main portions by cross-faulting. The central of these, the "Chinaman Ore-body", was a great, lenticular replacement deposit, occurring on the hanging-wall side of the almost vertical channel. Its dip in the higher portions was about 70° in a direction approximately west, becoming steeper at lower levels. It varied in width from a few feet to over 100 feet of solid ore, maintaining on some levels an average of 50 feet over a distance of 1,000 feet. Generally it consisted of a fine-grained, intimate mixture of galena and zinc blende, with chalcopyrite in places, often in parallel bands. It contained

[93] Gen. Rep. Rec. 73, 73-74 (1938).
[94] J. Coggin Brown, Rec. 56, 89 (1824).
[95] The earliest authentic records date the commencement of these operations from 1412, A.D.
[96] J. Coggin Brown. Rec. 48, 126 (1917).

several million tons of rich ore, of which a typical assay was; 26·2 per cent. of lead, 16·6 per cent. of zinc, 0·5 per cent. of copper, and 22.2 oz. of silver to the ton. The hanging wall was more or less irregular, but the foot wall was ill-defined and here, there was a gradual passage from the solid mixed sulphides of lead and zinc, to a second-grade ore composed of dark tuffs and breccias infiltrated with silica and containing bands, nests and strings of sulphides, in which the metallic contents gradually diminished.[907]

North of the cross-fault limiting the Chinaman ore-body in that direction, were four distinct lodes, three of which were doubtless originally connected with it. The most westerly, known as the "Burman Lode", was a thin, regular vein of lead-zinc-silver ore. Parallel to it and some 100-150 feet to the east, the "Shan-Palaung Lode" was noteworthy by reason of its high copper content. A third lode lay still further to the east. At a considerable distance to the east and north of the Shan-Palaung Lode, its nearest neighbour, was the "Chin Lode", a sporadic and perhaps independent deposit of copper ore. In 1929, exploration beyond the southern faulted end of the Chinaman ore-body, revealed the "Maingtha" ore-body which, in its turn, was opened up and mined.

The main road into the Bawdwin mine was by Tiger Tunnel, 7,250 feet long, itself the 6th level below the surface at Bawdwin. Marmion's shaft, which was sunk from the surface, in country rock to the west of the Shan ore-body, has fourteen levels at intervals of from 120 to 150 feet, connected of course with the rest of the mine.

Ore deposition reached its maximum in the congenial rhyolitic tuffs, the sedimentary rocks exercising a baneful influence, causing splitting and a restriction of the metallic minerals to narrow channels in place of the widespread mineralisation in the more favourable ground of the higher portions. For these reasons the Chinaman ore-body diminished in depth as sediments became more prevalent and in 1933 it was announced that "the ore extended to within 30 feet of the 10th level, where the conditions for mineralisation became unfavourable owing to the closing in of sediments on both sides of the mineralising fissure". Later additions to the ore reserves come from developments in the Maingtha section and from lateral exploration in the higher levels. By 1938, such development was approaching completion, and the ultimate tonnage of ore remaining to be extracted was estimated at 4,750,000 tons.

The ore-bodies have been deposited in the kaolinised and chloritised tuffs, but the rhyolite flows and other accompanying rocks, especially the grits, have been affected by the mineralisation. The ore does not occur in veins or lodes but as impregnations in bands of the country rock, usually a coarse rhyolitic tuff; the impregnation takes the form of nodular masses of finely crystalline galena, associated with zinc blende in which specks of copper pyrites are disseminated, or as granules in the felspathic grits. In all rocks, whether

[907] This and the following three paragraphs are reproduced almost verbatim from information very kindly supplied by Dr. Coggin Brown.

tuff, rhyolite or grit, there has been replacement of the felspar by galena and other sulphides. carried in hot solutions up from below through an intensely sheared and crushed zone ; in the final stages the quartz grains were also attacked, and partially or entirely replaced. The more important constituents of the Bawdwin ores are galena and zinc-blende. often finely intergrown and banded together ; with them occur pyrite and chalcopyrite. Amongst the minerals found are, native silver, native copper, galena, chalcocite, covellite, melaconite, zinc blende, calamine, chalcopyrite, pyrite, malachite, azurite, anglesite, cerussite, massicot, pyromorphite, erythrite, goslarite, brochantite and barytes ; anglesite, cerussite, malachite and azurite, probably derived from the sulphide ores, are comparatively common in some of the open workings. From a study of polished sections under the microscope, Dr. J. A. Dunn has recently recognised small quantities of the following rarer minerals ; gersdorffite, a sulpharsenide of nickel, NiAsS ; freieslebenite, a complex sulphide of silver, lead and antimony, $2Ag_2S.3PbS.2Sb_2S_3$; pyrargyrite or ruby silver ore, a sulphide of silver and antimony, $3Ag_2S.Sb_2S_3$; and perhaps tetrahedrite, grey copper ore, $3Cu_2S.Sb_2S_3$. The gersdorffite is cobaltiferous. Dunn suggests tentatively the following order of deposition ; pyrite, zinc blende ; gersdorffite ; chalcopyrite ; freieslebenite and pyrargyrite ; galena and the doubtful tetrahedrite.[98] Strings and nests of white quartz and small amounts of calcite are frequently observable in the disturbed zone ; beds of massive barytes are also of common occurrence but are not found in direct association with the galena.

The hypothesis that the hot ascending solutions responsible for the Bawdwin mineralisation may have emanated from the underlying magma of the Tawng-Peng Granite, has received no conclusive confirmation, nor is it certain that the deposition of similar ores which took place in other parts of Burma as well as in Yunnan and Tongkin after the accumulation of the Plateau Limestone, is of the same age and character as that seen at Bawdwin. Dr. Coggin Brown draws attention to the fact that the veins of argentiferous galena, stibnite or copper ore, found in several places in the Plateau Limestone, partake more of the character of water deposits laid down in fissures and having no direct connection with intrusive rocks ; this mineralisation may be presumed to have taken place at some time between the Uralian and Middle Permian epochs. The present state of our knowledge may be summarised as follows : (i) after prolonged search, no occurrence of the Tawng-Peng Granite intruding any rocks younger than the Chaung Magyis has been found ; this is inconclusive negative evidence in favour of a pre-Palæozoic age for the Tawng-Peng intrusion ; (ii) the proximity of the Bawdwin mineral deposits to the Tawng-Peng outcrop suggests a connection between the two, but this connection has not yet been proved ; (iii) the age of the rhyolites and tuffs among which the Bawdwin minerals are found is early Palæozoic (Ordovician), than which, therefore, the mineralisation cannot be older ; (iv) the identity of

[98] Rec. 69, 473 (1935).

the minerals found at Bawdwin with those occurring in veins in the Plateau Limestone is responsible for the hypothesis that they are all of the same age, but again, there are differences in the mode of occurrence, and the hypothesis has not yet reached the stage of proof. If we accept the correlation of the Bawdwin with the Plateau Limestone mineralisation, and also the hypothesis that the former was a direct and immediate outcome of the Tawng-Peng Granite intrusion, we must assent to the conclusion that the granite dates from the Upper Carboniferous or early Permian epochs not much later than that of the Himalayan Central Gneiss.

The Mohochaung Mines.—Some 25 miles northeast of Bawdwin are the old Chinese lead and silver mines of Mohochaung. As regards mineral character, the ore-bodies, though insignificant from a commercial point of view, are exactly similar to those of Bawdwin, and occur in sandstones and shales which are probably contemporaneous with the Bawdwin sediments. No rhyolite is present, but a coarse muscovite-biotite granite crops out about 3 miles to the West.[99] It is a possible hypothesis, as Mr. M. H. Loveman suggests, that the granite exists at some unknown depth below the ore bodies at Mohochaung as well as at Bawdwin and that the mineralising solutions are to be ascribed to the influence of the granite, though there are no actual facts in direct support thereof.[100]

North Hsenwi.—Argentiferous galena used to be mined from the Plateau Limestone near Lashio in the N. Shan States during the early days of the lead-slag smelting at Nam Tu;[101] nearly 6,000 tons of ore were extracted in 1909.[102]

Hsipaw State.—Specimens of galena with crusts of cerussite, with a little quartz in places, have been received from a locality about four miles west of Namsaw.[103] Galena is said to be scattered through grey finely crystalline limestone at Man Paw, 12 miles east of Mong Tung, the capital of the sub-State of the same name.[104] Specimens of stibnite, largely converted into cervantite, have been received from the sub-State of Hsum Hsai (Thonge), from a locality in the Ye-U circle.[105] Pieces of grey schistose slate and vein quartz with sparsely scattered chalcopyrite, abundant films of chrysocolla and some malachite, were obtained from near Letpandaw village in the sub-State of Möng Lông, Kaing-gyi circle.[106]

Mandalay.—Argentiferous galena used to be mined from limestones belonging to the Naungkangyi series (Ordovician), at Taunggaung, about 20 miles northeast of Mandalay.[107]

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[99] J. Coggin Brown, Rec. 56, 89-90 (1924).

[100] J. Coggin Brown, Rec. 56, 90 (1924); M. H. Loveman, Bull. Amer. Inst. Min. Eng. No. 120; p. 2120-2143 (1916).

[101] J. Coggin Brown, Rec. 56, 90 (1924).

[102] T. H. D. La Touche, Mem. 39, pt. 2, 378 (1913).

[103] Rec. 33, 234 (1906).

[104] L. L. Fermor, Rec. 33, 234 (1906).

[105] L. L. Fermor, Rec. 33, 234 (1906).

[106] L. L. Fermor, Rec. 33, 234 (1906).

[107] J. Coggin Brown, Rec. 56, 90 (1924); T. H. D. La Touche, Mem. 39, pt. 2, 378 (1913).

In small reticulated veins disseminated through the mass of the Plateau Limestone, near Maymyo, occurs chalcocite with smaller quantities of bornite and a little chalcopyrite; the ore is often associated with barytes but the usual gangue is calcite. In the vicinity of and parallel to these copper-bearing beds are several galena veins which have been worked to a considerable extent by the Shans; some of the galena is disseminated but most of it is in irregular bunches. The silver content of both the galena and the chalcocite is high.[108]

Older granites in Yamethin.—A granite, recorded by Clegg 41 miles south of Yamethin on the main Rangoon-Mandalay road, is described as identical in mineral composition and characteristics with the Kabaing Granite.[109]

Among the foothills of Mt. Pima a vein of argentiferous galena, reported to be from 3 to 30 feet thick, was opened up in 1908; after the extraction of some 2,500 tons of ore in the following year the mine was closed.[110] At several other localities in this district galena has been noted in quartz veins intersecting the Chaung Magyi rocks.[111]

Mawson (Bawzaing).—The sub-State of Mawson or Bawzaing has produced small quantities of lead and silver for many years. The number and extent of old Chinese pits and mines and scattered accumulations of lead slags bear witness to the existence of an indigenous mining and metallurgical industry which must have flourished here for centuries over a considerable expanse of country,[112] and is reputed to be older even than that at Bawdwin.[113] The slag heaps left by the Shans and Chinese, who were interested only in the silver, have been exploited by European methods for lead, the percentage of which is sometimes well over 40. The ore is found beneath a surface covering of red residual clay differing in no way from the "terra rossa" of the northern Shan States, in yellow clay filling clefts and fissures in a limestone series of Palæozoic age to which the name of Mawsön series has been assigned. This series, which has already been described (p. 623), comprises argillaceous limestones and calcareous shales overlying mudstones, shales and sandy shales. The limestones are generally hard, compact, homogeneous, calcite-veined and finely crystalline. Fossils are rare but the few collected from the series are enough to demonstrate its Ordovician age. The limestones contain interbedded bands of calcareous shale and arenaceous material, and it is within a brecciated zone of such rocks that the mineralised fissures lie.

Modern mines have been opened up,[114] and the main ore body, the Bawzaing Ore Body, is found in a wide irregular nearly vertical fissure with ragged walls, striking obliquely across the enclosing

[108] J. Coggin Brown, Rec. 56, 90 (1924).
[109] Gen. Rep. Rec. 71, 63 (1936).
[110] J. Coggin Brown, Rec. 56, 91 (1924).
[111] Gen. Rep. Rec. 59, 48 (1926).
[112] J. Coggin Brown, Rec. 56, 91 (1924).
[113] Gen. Rep. Rec. 59, 46 (1926).
[114] Gen. Rep. Rec. 63, 44 (1930).

rocks which dip at from 30° to 60°. On either side occur smaller parallel fissures. The main fissure is filled with mineralised clay containing very numerous irregular blocks of limestone of all sizes. Within the fissured zone there is an ore shoot, roughly lenticular in section, with a decided pitch to the south, and varying greatly in width up to a maximum of 70 feet. Other ore zones are known but are mostly smaller. Sometimes the fissures are practically closed and the adjacent beds show distortion.

The clefts and fissures are not always parallel to one another, but sometimes cross. They are the relics of numerous original veins, and the irregularly distributed blocks and fragments of galena, varying from the size of a pea to masses 3 feet across, are the undissolved remains of these veins. An occasional galena-barytes vein or an insignificant veinlet of galena with calcite or quartz is sometimes observable, and galena is sometimes found disseminated in the limestone by replacement. The ore is almost free from zinc and copper, and the silver content, which particularly attracted the old native workers, is very variable. Projecting ledges in the lumps of ore have suggested to Coggin Brown that deposition took place in approximately perpendicular systems of small joint planes. With few exceptions the deposits have been profoundly modified by subsurface decomposition and brecciation. The fissuring, which strikes generally N.-S. and has been traced for over 33 miles, is thought to be the result of uplift caused by intruding granite. Whether mineralisation of the contents of the fissures was another result of igneous activity or not is uncertain. The lead ores lie very largely, though not entirely, in the Mawsön series.

Probably in similar thin veins antimonial tetrahedrite with azurite and malachite are known to occur at a number of isolated places in Mawsön. An occurrence of malachite is reported at Kyauktap (Kyauktat).

Mawk-Mai.—Some ten miles S. S. W. of Mongnai, in the Southern Shan State of Mawk-Mai, are some old deserted silver mines or pits, excavated in loose material filling fissures in the Plateau Limestone. Small nodules of galena are observable in the soil or clay in these fissures.[115]

Pindaya.—Stringers and thin veins of galena have been observed by V. P. Sondhi in an argillaceous limestone southeast of Alechaung, in Pindaya, one of the Southern Shan States; a few old prospecting pits exist in the vicinity and pieces of slag are to be found in the neighbouring stream-bed.[116]

Myitkyinha.—In the Jade Mines area granite occupies small groups of thickly forested hills, or scattered bosses and tors, to the west of the Namya and Indaw Chaungs. The hill ranges between Nanyaseik and Manwe are entirely made up of this granite with large and irregular inclusions of marble or crystalline limestone. It is generally of medium grain but coarse and fine varieties are recorded by

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[115] J. Coggin Brown & V. P. Sondhi, Rec. 68, 162 (1933).
[116] Gen. Rep. Rec. 66, 63 (1932).

Bleeck.[117] The intrusion is probably of bathylithic type and is in places foliated or banded. The predominant type is a biotite-potash granite, pink or grey in colour, grading to quartz-augite monzonite or quartz-biotite monzonite. Both light and dark mica occur, while orthoclase and oligoclase are frequently intergrown to form microperthite. Sometimes the quartz has a vermicular structure with minute inclusions of felspar. Basic segregations of dioritic character are sometimes abundant in the rock which is also traversed by numerous veins of aplite and pegmatite. Chhibber has suggested a Mesozoic age for this granite.[118]

On the Shweli-Nmai Hka divide in the northeast corner of the Myitkyinia district, limestones and shales, seemingly identical with rocks of Ordovician and of Devonian age in Western Yunan, appear to be isolated among the granites and true metamorphic rocks of the Frontier ranges between Hpimaw and the Lagwi Pass.[119] "At the Chinese galena mines of this vicinity a fine-grained, silicified and chloritised tuff is in contact with white crystalline limestones which are believed to be altered Palæozoics, while the contact zone on both sides is veined and sparsely impregnated with galena carrying small amounts of silver (5-10 oz. per ton). Veins of slightly cupriferous pyrites are also found, frequently 10 feet and more across, which bear subsidiary veinlets of galena. Near the contact zone there is a peculiar calcite-mica-magnetite-pegmatite carrying occasional galena, pyrite and chalcopyrite". The deposits do not appear to be large.

The copper deposits of the Tangbalung reserve in south Myitkyina west of the first defile of the Irrawaddy, perhaps belong to the same mineralisation period. For two years they produced small tonnages of ore.

Bhamo.—Abandoned galena mines exist at Ponsee in the district of Bhamo.[120]

Putao.—Murray Stuart has distinguished three granites in the Putao district of north Kachin, the Nam Tamai granite, the Putao granite and the Taron granite. What their relationships are is not known, but deposits of galena occur close to the Tamai and Putao granites, and the suggestion naturally arises that one or both of these intrusions may represent the Tawng-Peng Granite ; the Taron granite may be younger.

The Tamai granite contains much more free quartz than the others and generally little or no biotite. Arranged in thick bands, it occupies the centre of the Tamai valley, flanked to the southwest by highly siliceous limestones, and passing along its northeastern margin into a hybrid complex of schists injected with the granite magma ; this hybrid frequently contains flakes of graphite in the *lit-par-lit* layers. The silicified limestones may be an outlying patch

[117] Rec. 36, 266 (1907).
[118] Gen. Rep. Rec. 63, 99 (1930).
[119] J. Coggin Brown, Rec. 56, 92 (1924).
[120] J. Coggin Brown, Rec. 56, 93 (1924).

of metamorphosed Palaeozoic rocks belonging to the Shan-Yunnan province;[121] in them occur a number of sparsely disseminated galena-pyrites veinlets and impregnations, probably along a line of fracture and of no economic value. The galena has been worked by the Nungs.

The mountain ranges on either side of the Nam Tisang valley, and nearly all the mountainous country at the head of the Nam Tisang and Nam Kiu, and northeast of the Putao plain, in which lies Fort Hertz, are occupied by the Putao granite, a biotite granite with white felspars, soft and decomposed at the surface. For some distance outwards from the plain, it shows foliation and passes in places into a kind of quartzose gneiss without mica; away from the plain the foliation disappears and in the Nam Ti valley the rock becomes porphyritic with large phenocrysts of felspar. In the granite, at the head of the Gum Ti, is a vein of argentiferous galena, which has been worked by the Chinese; in the same granite is another small deposit of galena on the western slope of Lang Razi, high up on the divide between the Nam Kin and the Nam Tisang. In all cases these galena veins are seldom as much as one inch in width.

The Taron granite, which is also a biotite granite, forms a high mountain ridge along the divide between the Nam Hat and the Nam Tamai, and is seen at the junction of the Nam Tamai with the Taron; a southerly branch of the granite outcrop separates the Nam Hat and Nmai Hka valleys.

The intrusive igneous rocks of this region include, besides various granites and syenites, diorites, andesites, pyroxenites and peridotites, the last mentioned types serpentinised and chloritised in places. Whether there is any genetic relationship between all these rocks is not yet known. The hornblende andesite appears to be intrusive into both the Putao and the Nam Tamai granites.

Lower Chindwin.—The granite found near Okkan, in the Lower Chindwin district, is probably of late Tertiary age, and is a coarse-grained, white intrusion composed of quartz and felspar in equal amounts, with a little hornblende; it weathers to a crumbling white earth.[122] The boss west of Chindaung is speckled with glistening biotite and may be of the same age; it is in contact with grit and sandstone which are believed to belong to the Irrawadian (Pliocene) and appear to be hydrothermally affected by the intrusion. South of Chindaung the hypabyssal phase of the Okkan granite is represented by a compact granophyre with spherulitic texture.

Yunnan.—According to Coggin Brown[123] granites of various ages are known to occur in Yunnan, including the pre-Palæozoic intrusions into the Archaean rocks of the Burma-China frontier ranges and elsewhere, and the batholiths responsible for the rich tin ore deposits of Ko-chiu in the southwest of the province. The latter are believed

[121] J. Coggin Brown, Rec. 56, 92 (1924).
[122] Gen. Rep. Rec. 61, 107 (1928).
[123] Private Communication.

to have been accompaniments of the Yenshanian movements, using the term to include the orogenic disturbances of the late Jurassic and early Cretaceous. The greater part of the granite massifs of Indo-China are formed of batholiths of a monzonitic character and of Upper Carboniferous or Lower Permian age; in addition to these, pre-Palæozoic granites are known, while in central Indo-China another series, probably of Mesozoic age, has been recorded.

Tavoy Granite in Tavoy.—The total area taken up by granite outcrops in the Tavoy district is little inferior to that occupied by the Mergui rocks. There are six major intrusions of boss granite, with the longer axes parallel to the strike of the sedimentary rocks and the mountain ranges. The main features of the topography are determined by the granite bosses, which have all produced high ranges and rugged mountain masses on either side of the valleys of Mergui rocks. With the exception of the tourmaline-pegmatites, the various intrusions that have originated from a common magma, are of the same age, and are almost undoubtedly continuous with one another underground. All the major granite bodies are markedly elongated in a direction parallel to the general strike of the country, *i.e.,* N.N.W.-S.S.E., most of their lobes extending in the same direction.[124] The Frontier intrusion forms the high continuous Bilauktaung range which divides Tavoy from Siam; its outcrop becomes broader and higher towards the north, in which direction it probably unites with the outcrop of the Coastal intrusion. The Mergui sedimentaries extend for long distances into the heart of the Frontier boss. According to Brown and Heron there is reason to believe that the exposures of granite are but the denuded tops of dome-shaped cupolas or the blunted edges of wedge-like masses, the trend of which is that of the mountain ranges and fold axes. The numerous elongated exposures of the granite bosses are seldom traversed by streams of any importance. This is so noticeable that, as suggested by Brown & Heron, it seems possible that the present drainage system was modified, if not initiated, by the granite bosses rising beneath the older sedimentary strata and pushing them into bulges and troughs. Had the intrusion of the granite had no effect on the old denuded land surface of the Merguis, it is to be surmised that the drainage system of the latter would have persisted and would have impressed itself on the granite bosses as well as on the deeper-lying Mergui beds as they became laid bare by denudation, in which case we should expect more frequent transverse crossing of the granite bosses by the present-day streams.[125]

The granite of Tavoy varies considerably in grain and texture but is of very uniform mineralogical composition, not only all over the district but as far north as the Yamethin district and as far south as Victoria Point, the southernmost extremity of Burma. From the southern Shan States to Mergui there is the acid granite, with abundant quartz, orthoclase, frequently as large phenocrysts, acid plagioclase, sometimes microcline and micropegmatite, and mica—

[124] J. Coggin Brown & A. M. Heron, Mem. 44, 184 (1923).
[125] J. Coggin Brown & A. M. Heron, Mem. 44, 200 (1923).

usually biotite.[126] Two samples of the rock from Tavoy showed a content of 74·65 per cent. SiO_2 in one case and 78·14 per cent. in the other.[127] Hornblende is rarely present and then only in small quantity. Except in the veins, accessory minerals are remarkably scarce. Iron pyrites, probably original, is locally common. The heavy concentrate from stream sands and granite soils near contacts with the Mergui bed show ilmenite, magnetite, garnet, zircon and a form of monazite, and these are probably sparsely distributed in portions of the granite. The cassiterite, wolfram and in rare cases topaz, found in stream gravels and surface soil in or near mineralised areas, have originated mainly from the quartz veins and greisens, but may also be present as disseminated grains in true granite. In analyses of two typical varieties of the rock C. S. Fawcitt could detect neither tin nor wolfram ; one of them, however, a very fine-grained granite, was found to contain small quantities of molybdenum and bismuth. An analysis of a granite porphyry, on the other hand, showed 0·15 per cent. of tin.

In the central parts of an intrusion the granite is generally coarse-grained and porphyritic. Towards the periphery there is a gradual transition to a finer textured and more uniform rock, biotite becomes scarce or absent and gives place to muscovite, while the proportion of quartz increases ; there is little of the nature of a chilled edge at the contact with the intruded Mergui beds. In a few cases a slight fluxion-structure or pseudo-foliation near the contact with the intruded rock, due to slight motion in an almost consolidated magma, has been mistaken for gneiss ; here the finer crystals have been drawn out in lines curving round the larger felspars. This structure is seen on a large scale in the coastal area where exposures caused by the penetration of the sea happen to be unusually clear. Here zones of extremely coarse material, poor in biotite, alternate with others which are fine-grained and highly biotitic ; the direction of these bands is undulating in detail but approximates in general to the prevailing strike. The minerals show no sign of strain or deformation, and the bands differ from one another only in the proportion of biotite ; it would appear to be not a genissic but a fluxional effect due to the segregation of biotite. Small faults and slippages are common but the dynamic metamorphism resulting therefrom is unimportant. Evidence of secondary movement in the fissures in the forms of slickenside, crushed quartz and contorted mica, is not uncommon but the granite responsible for the mineralization is exceptionally uniform in character over great areas.[128] The granite sends off into the surrounding sedimentaries a few small apophyses of fine-grained granite and felspar porphyry, but these are seldom seen.

With few exceptions the granite is sparingly jointed, and weathers in great curving surfaces of bare rock and not in the fantastic sculpturing typical of a region of low rainfall and considerable temperature variation. The coast is fringed entirely by granite which forms

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[126] J. Coggin Brown & A. M. Heron, Rec. 50, 119 (1919).
[127] A. W. G. Bleeck, Rec. 43, 59-60 (1913).
[128] J. Coggin Brown, Rec. 49, 31 (1918).

headlands and bays but no cliffs. Decomposition penetrates to great depths, in places to as much as 100 feet. The surface soil over the granite is much lighter in colour and more sandy than that formed by the Mergui beds.

Xenoliths of Mergui beds of all shapes and sizes are very common in the granite, especially near the peripheries of intrusions ; they show surprisingly little alteration, merely a slight marginal bleaching and silicification. Brown and Heron remark that in the granite itself there are few indications of earth stress.

Pegmatites and Quartz veins.—Pegmatite veins and quartz veins occur in both the granite and the Mergui sedimentaries, those in the vicinity of the contact being responsible for the mineralization which has made Tavoy and Mergui famous for their tungsten and tin ores. The pegmatites which are more deeply seated in the granite are less often seen, and occur in large coarse veins up to 15 feet wide or in small fine veins. The acid type is made up of quartz, white or grey, rarely pink felspar, with or without a little biotite ; in the more basic type biotite is in excess. The two types are represented in the light and dark banding in the granite bosses, the only difference between the two forms of occurrence being that in the case of the veins the differentiated material has been injected into fissures instead of remaining where it segregated. Segregation patches of the basic type are to be seen in the granite. A more advanced stage in differentiation is exemplified in the quartz veins. Some basic intrusions of heterogenous composition may be incidentally mentioned here, but are extraneous in origin to the granite ; they run irregularly and vary greatly in size ; an exceptionally wide one being 20 feet across. Lastly there are the tourmaline pegmatites which penetrate the granite and are later than the ordinary pegmatites and quartz veins ; by fractional crystalization these give rise to quartz-felsper veins and pure quartz veins without tourmaline which are indistinguishable from the earlier pegmatite veins and quartz veins belonging to the granite, except in so far as they are of later age and cut across the latter. So much for the deeper-seated veins ; we have now to consider the much more important contact veins in which mineralisation has taken place.

Mineralisation.—The mineral deposits of Tavoy have been studied in great detail by Brown and Heron. In the admirable memoir on the subject[129], they note that wolfram and cassiterite occur in Tavoy in five different ways: (i) as segregation deposits in muscovite granite ; (ii) in pegmatite veins with quartz, felspar, mica, fluorite, scheelite, molybdenite, the sulphides of iron and copper and rarely the sulphide of lead ; (iii) in quartz veins, nearly always with mica and pyrite, often small quantities of fluorite, sometimes molybdenite, chalcopyrite, pyrrhotite and stibnite, and rarely galena, arsenopyrite, zinc blende, bismuth, bismuthinite, siderite, calcite and topaz ; (iv) in greisen with mica and pyrite ; (v) in residual, detrital talus, and, in the case of tin, in alluvial and placer deposits.

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[129] Mem. 44, pt. 2 (1923).

By far the largest proportion of the wolfram occurs as irregular aggregates with no outward crystal forms, varying in size from small pieces, a few inches in diameter to large masses of several hundredweight: in the larger pieces intergrowths with quartz are always found. The hydrous tungsten oxide, tungstite, is found in all wolfram veins exposed to circulating ground waters, but is too easily decomposed to be of economic value. Scheelite is found in too insignificant quantities to be of any economic importance. Cassitertite nearly always accompanies wolfram in Tavoy. Beryl was observed in one of the granite bosses, and has been recorded from the wolfram veins of the Yamethin district.

The occurrence of wolfram and cassiterite as true accessories in granite proper is of mere academic interest, both minerals are far commoner in the fine-textured aplite veins of quartz, orthoclase and a little muscovite, which sometimes penetrate the main granite masses and are a little younger than their hosts. Wolfram and cassiterite also occur, sometimes in sufficient quantity to be a profitable source of ore, in the greisens or narrow bands of quartz-mica rock formed by alteration of the granite adjoining quartz veins. Yet again the two minerals are obtained sometimes in commercial quantities from the pegmatite veins.

Fissure veins of quartz are responsible for the great bulk of the concentrates produced in Tavoy. These mineralised veins are typical of the vicinity of the contact between the granite and the intruded Mergui sediments, and are found along this contact or in the granite or the sedimentary rocks on either side. They are noticeably more characteristic of the contacts with the small granite outcrops than they are of the contacts with the large expansive outcrops of the same rock. Brown explains this as a result of mineralisation being more or less restricted to the uppermost surfaces of the intrusions. If we regard the granite masses as approximately wedge-shaped, narrowing to the tops of intrusions and broadening out below, we may look upon the size of the granite exposure as being some measure of the amount of erosion; in other words the smaller the exposure of granite the nearer is it to the top of the particular boss or upwardly projecting tongue it represents[130]. These veins have been produced by the inflling of fissures and occur often in parallel groups, often in a series of overlapping lenses the individuals of which are frequently irregular, splitting up or re-uniting. The walls are clear and well defined. The quartz of which the vein is composed is usually dense, milky white and very compact; mica is nearly always present and very often sulphides. Alteration of the granite walls to greisen is practically universal. In the granite fractures are found to be longer and better determined than they are in the Merguis. There is every gradation from great veins traceable for miles on the surface to insignificant ore-bearing stringers. The strike of the majority of the veins coincides with that of the country, and such veins are generally very uniform in thickness and structure

[130] J. Coggin Brown, Rec. 49, 31 (1918).

over long distances[131]. Some on the other hand, run transversely; these are not at all uniform in thickness, do not persist for any distance in a transverse direction, and tend to split into numerous little ladder veins which constantly separate and reunite. There has been a tendency for deposition to concentrate in the thin stringers which, in comparison with their siize, are often excessively rich in ore. The hade of the veins is usually steep, but not invariably so. Composite veins are not rare, some veins show evidence of successive reopenings, the sulphide minerals being then largely secondary to the wolfram and cassiterite[132]. Contrary to former opinion columbite is not found[133]. The commonest variety of mica in the veins is muscovite[134].

As in other parts of the world, the wolfram is distributed in the veins in erratic bunches or patches. The richer veins contain between 2 and 3 per cent., of wolfram, the poorer veins between 1 and 2 per cent. The composition of the concentrates obtained varies but is approximately 55 per cent. WO_3 and 15 per cent. Sn.[135] With exceptions, veins in the granite usually carry more tin-stone than those in the sedimentary rocks. In the great majority of cases the deposition of the wolfram preceded that of the tin. The usual order of deposition in the veins was: molybdenite, wolfram, cassiterite, bismuth, bismuthinite, fowolled by the majority of the sulphides. Pyrites belongs to several periods of the processes of mineral formation. Fluorite, which has a wide though scanty distribution in the Tavoy veins, was one of the latest to be deposited. Contrary to the usual idea Brown and Heron found that wolfram is attacked and removed with comparative ease by both acid and alkaline solutions with the production of friable yellow tungstite or soluble alkaline tungstates, denudation being assisted no doubt by the perfect cleavage of the original mineral. Consequently, although found in eluvial or talus deposits at the base of hills, wolfram is not found in the water-sorted true alluvial deposits unless tightly enclosed in quartz; cassiterite on the other hand, being much more resistant, is found and worked in these river-sorted alluvial sands and gravels.

The winning of tin from the alluvial sands and gravels is a very ancient industry. With regard to wolfram, on the other hand, Tenasserim is a young field. Mining of a sort commenced in 1909, and in 1918 there were over 100 producing mines. During the Great War nearly 18,000 tons of wolfram concentrates, valued at something like £2,500,000 were exported from Burma, most of it coming from Tavoy. Most of the tin ore is shipped to the Federated Malay States for smelting[136].

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[131] A. W. G. Bleeck, Rec. 43, 63 (1913).
[132] J. Coggin Brown, Rec. 56, 97 (1924).
[133] J. Coggin Brown & A. M. Heron, Rec. 50, 120 (1919).
[134] Analyses by C. S. Fawcitt of various veins will be found in Rec. 43, 66-67 (1913).
[135] Min. Journ., Mar. 15th, 155 (1919).
[136] J. Coggin Brown, Rec. 49, 27 (1918).

Regarding the origin of the ores considerable difference of opinion exists. Brown & Heron's conclusions are that, although water may have played an important part in vein formation, in the great majority of cases it was of magmatic and only in a few cases of meteoric origin. Since pegmatites carrying wolfram and cassiterite exist and some of them pass laterally into quartz veins with the same metallic minerals, it is inferred that the veins in which the pegmatitic origin is not so clear, may have been formed under conditions approximating closely to those under which the pegmatites themselves arose.[137] In so far as pegmatites and aplites are correctly regarded as differentiation products of granites, it seems reasonable to look upon their metal-bearing contents as segregations from acid magmas to an equal extent. Brown & Heron conclude that the wolfram-cassiterite-sulphide deposits of Tavoy were formed partially under conditions closely allied to strictly magmatic ones and were also formed by processes in which gaseous agencies, including compounds of fluorine and sulphur, to some extent played a part. Towards the end of the pegmatite period a hydrothermal phase supervened and a few of the veins were doubtless formed then. The stages, perhaps in some cases concurrent, are thought to have been all part of one continuous process, a direct sequence of differentiation or fractional crystallisation through a set of varying phases induced in the original magma by decreasing temperature. Bleeck's views are not dissimilar[138] and amount to the assumption that some of the mixed veins are of simple pegmatitic origin, while others are of hydrothermal and pneumatolytic genesis.[139]

The zone of mineralization of which the Tavoy occurrences form a part, extends from the far north of the Southern Shan States southwards through Burma and beyond it into Siam and the Malay States. The true western boundary of this mineral tract is at present unknown since the seam covers much of it ; the eastern has not yet been fully explored. Brown & Heron remark that, wherever granite intrusions, similar to those of the Tavoy area, occur, "there is a reasonable possibility of finding wolfram and cassiterite veins, provided that the portions of the parent rock which contained them originally have not been removed." The linear arrangement, which is a feature of the mineral deposits, is a result of the elongation of the granite bosses ; two such lines, for instance, are as much as 40 and 20 miles long.

The tourmaline pegmatites, which have already been referred to, are found in the vicinity of contacts as well as in the central parts of the granite, invading both Merguis and granite, cropping out as parallel vein of all sizes, usually in groups, running in the direction of strike. In the Tavoy district these contain no wolfram, cassiterite or sulphide minerals, and have no connection with the metalliferous veins which, in their turn, contain no tourmaline[140] ; furthermore, with

[137] Mem. 44, 330 (1923).

[138] Rec. 43, 71 (1913).

[139] J. Coggin Brown, Rec. 49, 27 (1918).

[140] Some of the metalliferous veins further north and also south in the Mergui district do contain tourmaline ; in the latter district they are the principal source of tin ore.

one exception, all the known occurrences of tourmaline-pegmatite in the Tavoy district are at a considerable distance from the wolfram-bearing or tin-bearing areas. They are much rarer than the ordinary pegmatites.

The Tavoy Granite in Mergui.—As in the case of Tavoy, parts of the frontier region of Mergui remain unexplored, but the proportion of exposed granite in the latter district is much less than it is in the former. It is more prevalent in the archipelago than it is on the mainland, and some of the larger islands such as Domel and Sellore, and their smaller continuations, consist entirely of exposures of this rock. One of the bosses on the mainland, that to the S. E. of Mergui town, carries ores of tin and tungsten.[141] The outcrops of granite are arranged more or less linearly in three groups: one forming the frontier range which divides the drainage of the Tenasserim river from that of rivers flowing into the Gulf of Siam and extending to within ten miles of the sea;[142] a central chain, almost parallel to the coast, of disconnected outcrops protruding through the surrounding Mergui argillites as summits on a continuous subjacent range; and a western group, bifurcating towards the south, among the islands.[143] The boss to which the granite of Domel Island belongs is responsible for alteration of the Mergui beds seen on the neighbouring island of Kissaring (Kissaraing; Kittha-reng). The occurrences in the Ross & Elphinstone group of islands have already been mentioned.

The granite of the Mergui district differs from that of Tavoy only in minor details. These differences consist of a greater abundance of tourmaline, a more frequent occurrence of hornblende, and better developed jointing. The accessories, tourmaline and muscovite, are usually to be found along the peripheries of the bosses, replacing the biotite. Muscovite is present to such an extent in the small branching granite veins penetrating the mica schists of an island to the west of Bokpyin in Mergui as to give the island the name of "Silver Island". Cassiterite occurs as a constituent of the smaller bosses. According to Sethu Rama Rau tourmaline and muscovite sometimes form the major part of the granite, with or without subordinate cassiterite. Xenoliths of the sedimentary group are characteristic of the peripheries. The "foliation with '*augen*' structure", alluded to by Sethu Rama Rau as being present in the granite of some of the islands, is in all probability an example of the fluxion-structure seen in the granite of Tavoy near its contact with the intruded sedimentaries by Brown & Heron (p. 1452). The developed jointing facilities weathering.

Quartz porphyries form an important factor in Mergui, especially on Johnny, Paton, Allan and neighbouring islands.[144] Dykes of this rock are observable at the margins of the granite, mostly along the sea coast or in the islands. The rock is massive in texture, cream or

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[141] Gen. Rep. Rec. 54, 51 (1922).
[142] Gen. Rep. Rec. 55, 32 (1923).
[143] S. S. Rama Rau. Mem. 55. 35-36 (1930).
[144] Gen. Rep. Rec. 33, 54 (1909).

purplish grey in colour, and consists of phenocrysts of quartz and felspar in a compact, very fine groundmass.

The pegmatites, as in Tavoy, are either of the same age as, or little later than granite, and belong to the same magma. Their outcrops form disconnected lenticular masses, but preserve a regularity in direction coinciding with the strike of the sedimentary rocks which is N. N. W.-S. S. E. They consist of quartz, orthoclase and muscovite, with accessory tourmaline, garnet, cassiterite, muscovite and oxides of iron but apparently no wolfram.[145] The residual and detrital deposits derived from the weathered pegmatite veins are the chief source of tin in the district. Pegmatite in which muscovite is abundant is often rich in cassiterite; pegmatite without muscovite is usually poor in cassiterite. Tourmaline-muscovite pegmatites, locally carrying cassiterite but never wolfram, are common in parts of the Mergui district.[146]

As in Tavoy quartz veins represent the last phase of igneous action and traverse not only the granite and sedimentaries but also the pegmatite veins. Almost all the successful tin and wolfram mines of the district lie on the slopes of the hills forming the central granite boss southeast of Mergui town and in the adjoining country through which run quartz and pegmatite veins. In some of the tin mining areas there is no visible boss of granite, the quartz veins being associated with aplite and pegmatite dykes. In some of the islands neither granite nor pegmatite is to be seen, the Merguis being the only visible country rock in which the quartz veins lie. In one area exploited alluvial deposits appear to owe their presence to numerous small quartz veins with high cassiterite content, lying superficially at any rate, entirely within the Mergui outcrop, neither granite nor pegmatite occurring within some miles.[147] The typical mode of occurrence is in groups of parallel veins which are not continuous over long distances but pinch out or widen, producing lenticular patches with intermediate stringers. The veins, which always occur in groups and never singly, are anything from ½ inch to many feet across, the maximum, 15 feet, being at Tagu. In the argillites they lie parallel to the granite axes, but at the margins of the granite they are described as running in all directions and having the appearance of emanating from the granite. Gentle dips have been noted but the majority are steep. Veins in the sedimentaries are not as wide as those in the granite, and again it is the small veinlets and stringers which are richest in tin and wolfram. In the wolfram-bearing and tin-bearing veins is found the same association with the sulphides of iron, copper, arsenic molybdenum and antimony; all these minerals, with the exception of molybdenite and stibnite are abundant among the veins of Tagu and Maliwun.[148] Bismuth has also been observed. In one small reef, six inches wide, close to the Tagu area, a small pocket of stibnite was observed but no wolfram. On Maingay's island is an argentiferous

[145] Gen. Rep. Rec. 53, 20 (1921).
[146] Gen. Rep. Rec. 54, 52 (1922).
[147] Gen. Rep. Rec. 53, 20 (1921)
[148] Gen. Rep. Rec. 54, 51 (1922).

galena vein, about 2 feet wide but pinching out to an inch or two. Gold is found as a constituent of the quartz veins, sometimes associated with cassiterite, but not in paying quantities.

Greisen is found at the junction of the granite with the sedimentaries, on the walls of ore-bearing quartz veins, or as narrow segregated bands in the granite. It is composed of mica, chiefly muscovite and quartz, with or without very small quantities of felspar. The rock is usually rich in tin and wolfram ores and gives rich concentrates on sluicing. Tourmaline is generally associated with the tin ores in the greisen.

Xenoliths of the sedimentaries near the peripheries of bosses are much in request by tin miners since weathering at the junction yields rich eluvial deposits. Generally speaking granite with muscovite and tourmaline, either in bosses or as pegmatites, is most sought after as a probable source of tin and wolfram ; the hornblende variety is in disfavour and the biotite variety still more so. Although the granite is the ultimate source of the mixed wolfarm tin ores, it is the quartz veins lying in the Mergui sediments which are worked for the ores. In the Mergui district, although granite is widely distributed, the metalliferous ores have been found only in a few places.[149] All the Mergui wolfram deposits appear to carry cassiterite.

The extraction of wolfram dates from about 1909 only and received a great impetus from the Great War. Tin ores, on the other hand, have been sluiced during the last two centuries by Siamese and Chinese settlers. In the early days the tin ore was mostly smelted locally by the Chinese method and the metal exported as block tin. Today the ore is being exported to the Federated Malay States and the Straits Settlements where it is smelted. The tin mines of Mergui are described as lying on three parallel mineralised belts, two of them on the mainland and one in the islands. Most of these mines are in alluvial or eluvial deposits derived from the tourmaline-muscovite vein pegmatites which penetrate the biotite boss granite. The chief wolfram deposits of the Mergui district are near Palauk in the north, and at Tagu near the Great Tenasserim river, about 70 miles up from its mouth ; Tagu is one of the richest areas and is known for the width of its quartz veins some of which measure from 10 to 15 feet across, and all of which lie in granite. Maliwun is another well known area. Ilmenite, monazite, magnetite and garnet are obtained from the sands of the streams draining the granite ridge of Mergui island.

Amherst.—The typical granites of the Amherst district comprise pale, medium grained biotite granite and hornblende-biotite granite ; these rocks are remarkable for their abundant accessory sphene and epidote, but normally contain no tourmaline. The central tract is connected with the coastal boss of Tavoy. Near the boundary with the Mergui sedimentaries of the Taungnyo range, the granite of this district becomes banded and gneissose. The biotite granite of Thabut Taung is remarkably well jointed. Leicester records an extensive

[149] Gen. Rep. Rec. 53, 20 (1921).

development of micro-dioritic rocks and melanocratic micro-granites which occur in the hornblende-biotite granites as lenticular masses, wisp-like patches or veins, with a general N.W.-S.E. orientation. Ordinarily these veins cut the granite, but in places granite in the form of veins cuts the more basic types. Both are penetrated by small quartz veins and again by veins of aplitic biotite granite. Some of the smaller quartz stringers in the sedimentaries are tin-bearing.[150] The dark, fine-grained rocks are looked upon as differentiation products of the granite magma ; according to Leicester, they are arranged as lenticles and veins parallel to the strike of the sedimentaries. Within the metamorphic aureole the biotite granite frequently contains tourmaline, veins of the same mineral and micro-pegmatoid rock ; in places it carries quartz stringers with cassiterite.[151] As the contact with the sedimentaries is approached a characteristic zone of metamorphism becomes evident comprising variations which have the appearance of *augen* gneiss and banded granulite, the latter often garnetiferous. This is the Tavoy Granite which, in the Tavoy district, shows no banding unattributable to fluxion structure. Iyer describes the rock in Amherst as highly jointed and varying in texture from granitic to definitely banded gneissic types ; among, the latter is a streaky gneiss, with local slip planes, formed of a porphyritic rock with crushed phenocrysts arranged in regular bands, in a matrix of quartz, felspar and biotite, showing varying stages of crushing, granulation and to a small extent mylonisation.[152] Such phenomena appear to be something more than metamorphic changes induced on a prematurely consolidated granite margin by the persistent pressure of the magma behind it.

The gneiss of the Dawna range which, it has been suggested, may be of Archæan age, is quite different from the granite described above and from the Tavoy granite but a coarse tourmaline granite-pegmatite frequently intrudes both the gneiss and the accompanying schists.[153] In Siam the granitic rocks are to a large extent post-Triassic, according to Hogböm.[154]

Wolfram is said to occur near Ye to the north of the boundary between the Amherst and Tavoy districts, and also in the Dawna range on the Siam frontier, but has not been exploited. Alluvial cassiterite occurs in Bilugyun island at the mouth of the Salween, and at places on the eastern and western flanks of the Seludaung (Taungnyo) range. On Bilugyun the deposits are found on the lower slopes of ridges of argillite quartzite and grey slate which form the back-bone of the island.[155] These sedimentary rocks, belonging to the Mergui series, are penetrated by veins of coarse pegmatite (quartz, felspar and tourmaline with a little muscovite and garnet), of fine-grained and foliated tourmaline granite, and of drusy white quartz ;

[150] Gen. Rep. Rec. 61, 102 (1928).
[151] Gen. Rep. Rec. 63, 93-94 (1930).
[152] Gen. Rep. Rec. 72, 69 (1937).
[153] G. de P. Cotter, Rec. 55, 277 (1923).
[154] Bull. Geol. Inst. Univ. Upsala, 12, 111 (1913-1914).
[155] J. Coggin Brown & A. M. Heron, Rec. 50, 103 (1919).

the tinstone may come from any or all of these rocks but has actually been found in none of them. Garnet and ilmenite are present with the cassiterite in the concentrates obtained by panning the alluvium, and also large quantities of tourmaline. Around Sakangyi, where concessions have been taken out, the country is made up of quartzitic sandstones and argillites, underlain by intrusive granite. The tin mined around Mawpalaw Taung, east of Karokpi, is in lateritic eluvial deposits at the foot of a hill composed of red, buff and white sandstone and banded quartzite associated with shales and micaceous slates ; the ore chiefly a grey cassiterite, is apparently derived from small quartz stringers intruded into the sandstones during the period of the granitic intrusion of the province.[156]

A small much kaolinised pegmatite vein, rich in black cassiterite, is mined during the monsoon at Kunhnitkwe. It is a discontinuous vein, some 2 feet across at the thickest part, striking nearly N. W.-S. E., and following the bedding planes of the country rock which is made up of sandy shale and sandstone.

Several references are to be found in older literature to antimonite deposits scattered about the Amherst district. One of these is at Lekka Taung, some 23 miles south of Moulmein, where stibnite and cervantite occur in pockets in quartz veins traversing sandstone.[157]

More is known of the very large antimony-bearing veins of Thabyu, close to the Siamese frontier ; the largest of these is at least 20 feet across and 600 feet in length. The ore consists of stibnite, in bunches of radiating or parallel crystals, up to 4 and 5 inches long, and in massive aggregates ; for a depth of several inches oxidation has converted the sulphide to soft earthy antimnoy ochres, cervantite or stibiconite. The vein-stuff is a calcareous chert showing distinct brecciation and often a cellular structure due to localised solution and removal of silica or ore, by percolating waters. In the veins are frequently found small angular fragments of slate, like that of the walls but whitened and indurated by silicification.[158] The fine, black, uniform slates in which the veins occur are fissile varieties of the typical Mergui argillites.

There is no granite in the neighbourhood of the veins which are described as being different in character and origin from the typical wolfram and cassiterite veins of Tavoy, but there is nothing against the view that they are the hydrothermal equivalents of the igneous veins. Heron remarks that the Thabyu deposits are typical of the majority of the stibnite occurrences, and were deposited from water at a comparatively low temperature and at a moderate depth below the surface. The ore contains about 61 per cent. of metallic antimony.

Thaton.—The great mass of the eastern highlands of Thaton, culminating in the peak of Kyaiktyo (Chaiteo), is built up of biotite granite belonging in all probability to the Tavoy suite ; Kelatha hill,

[156] Gen. Rep. Rec. 61, 73 (1928).
[157] J. Coggin Brown, Rec. 56, 100 (1924).
[158] A. M. Heron, Rec. 53, 40 (1921)

a few miles distant, is composed of the same rock.[159] The Thaton granite was originally included by Theobald in his heterogeneous Martaban group, and has been found intrusive into quartzites, sandstones, argillites and grits of approximately Permo-Trassic age. The granite of Thaton carries tourmaline and is in places characterised by marked foliation and jointing with a N.W.-S.E. trend.

The cassiterite and wolfram areas of the Thaton district are all on a long ridge parallel to the railway from Pegu to Martaban. No actual cassiterite-bearing veins have yet been discovered.[160] The wolfram-bearing veins are in two well marked series, one in the granite and the other in the sedimentary series mentioned above. The mineralised veins in the granite are parallel to the N.W.-S.E. jointing therein, and dip to the N. E. They are all tourmaline-bearing and carry quartz, muscovite and probably felspar, being thus true pegmatites; in addition to the wolfram are the accessories pyrite, chalcopyrite, arsenopyrite and molybdenite. Four parallel veins close together, of an average thickness of not more than 4 inches can be traced for an unusually long distance of 2½ miles; beyond their southern termination, moreover, are two rather thicker continuations. The veins in the sedimentaries, which are found at some distance to the east of the granite and dip to the west at comparatively low angles, are thicker but much less continuous than those in the granite; these are of the normal Tavoy type in which quartz and wolfram are the chief vein minerals. There are two tin concessions at the extreme ends of the line of wolfram-bearing areas. One of these is so far entirely alluvial; in the other the deposits are eluvial, the tin being derived from small veins and stringers in the underlying sedimentaires. On the slopes of a range of the Thaton-Martaban hills, to the west of the railway line, a narrow quartz vein containing stibnite has been traced for 600 or 700 feet in slates already mentioned as presumably belonging to the Mergui series.[161]

Toungoo-Salween.—In the Yunzalin area, east of the Sittang river, a small boss of granite has been observed in one place intruded into beds identified as belonging to the Chaung Magyi series.[162] The intrusive rock is characterised by large phenocrysts of orthoclase in a matrix of quartz, oligoclase, biotite and muscovite. Slates and quartzites of the sedimentary series are seen to be caught up in the granite, whilst veins of granite and pegmatite radiate into the surrounding sedimentaries.[163] The granites of this area include, beside a medium grained potash granite a fine-grained soda granite and a hornblende-biotite granite.[164]

Karenni.—The well known cassiterite and wolfram mine of Mawchi lies in the southern portion of Bawlake, one of the Karenni States. The mineral veins were first found in a hill known as Keh

[159] Gen. Rep. Rec. 60, 81 (1927).
[160] J. Coggin Brown & A. M. Heron, Rec. 50, 105 (1919).
[161] J. Coggin Brown Rec. 56, 100 (1924).
[162] An identification requiring confirmation.
[163] E. L. G. Clegg, Rec. 30, 300 (1927).
[164] Gen. Rep. Rec. 61, 103 (1928).

Daung ("Tin Hill"), the top of which is composed of limestone forming part of a large lenticle of that rock. The sedimentaries of the area—limestones, sandstones, siltstones, slates, uncleaved argillites and conglomerates—have been assigned to the provisional Mawchi series, perhaps the equivalent of the Mergui.[165]

A long narrow hog-back of granite, extending N.N.W.-S.S.E., parallel to the grain of the sedimentaries, is intrusive towards the limestone and the accompanying argillites, fine sandstones and other deposits. Only a comparatively small area of the granite is exposed at the surface, and it is known to occur not far beneath at least seven miles north of the exposed edge of the outcrop and at least ten miles to the south of its southern exposed margin. According to Hobson, it has arisen along the western contact of one of the limestone bands, eating its way into the sediments on either side. The apex of the boss lies in the centre of the mine workings, and apophyses are given off from the parent mass into the surrounding rocks. The intrusion of the granite has produced a noticeable change in the regional strike of the invaded rocks and has opened up fractures at right angles to the local strike in the sedimentaries south of the limestone band. Such fissures afforded an additional opportunity for ore deposition at a late stage of the igneous disturbance, with the result that numerous veins carrying tin and tungsten often in considerable quantity were formed among the slates and sandstones, in addition to those which, as we shall see, rose up through the granite itself. The marginal portion of the limestone band has been turned up by the invading granite magma. Along the granite contact there is a narrow aureole of metamorphosed Mawchi sediments, and any signs of this metamorphic aureole encountered underground are an indication that the granite is close at hand.

The granite is described by Dunn as variable in texture and mineral composition, occasionally banded or gneissic, and affected by widespread kaolinisation. In the mine area the granite has undergone extensive tourmalinisation. Oligoclase and orthoclase are both present, the former the more abundant. Quartz is usually subordinate in amount except in the more sodic varieties. Rarely the orthoclase is intergrown with the quartz. Microcline may be more abundant than appears at first sight, since it seems to have been largely obscured by kaolinisation. Tourmaline is found throughout, sometimes to the exclusion of other ferromagnesian minerals. Biotite has been noted in a few specimens and scanty green hornblende in one case only. Other minerals are: secondary muscovite (gilbertite), lepidolite, fluorite in several specimens, calcite and minute prisms of what appears to be topaz in the altered types, pyrite, magnetite, and occasionally epidote. Porphyritic varieties of the granite are characterised by phenocrysts of oligoclase. Hobson records the following gradations of the granite: (i) a plain white aggregate of quartz and felspar, with an almost complete absence of dark-coloured minerals;

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[165] G. V Hobson, Trans. Min. Geol. Inst. Ind. Vol. 36, 41 (1941).

(ii) banded fine granite, the bands due to alternations of layers containing varying amounts of tourmaline ; (iii) spotted granite in which the spots are made up of small aggregates of tourmaline ; (iv) grey granites in which the dark colour is the result of a large content of disseminated tourmaline ; and (v) a quartz-tourmaline rock in which the silicate minerals have all been destroyed, leaving an aggregate of tourmaline with the original quartz of the granite in addition to that arising from the formation of the tourmaline at the expense of less basic silicates. The granite frequently contains noticeable quantities of cassiterite in grains closely associated with tourmaline, muscovite and fluorite, but never wolfram which is restricted to certain segregations in the granite. Tourmaline-quartz aggregations, which are by no means uncommon in the granite of the mine, often contain valuable amounts of cassiterite and wolfram. Some of the granite, in fact, is probably of economic grade if worked by cheap methods. Tourmalinisation and mineralisation are evidently intimately connected, and the presence of tourmaline usually indicates the presence of cassiterite and wolfram. The kaolinisation of the granite has been so acute that exposure of the rock to air—especially to moist air—causes its immediate disintegration.

Veins of aplite are occasionally seen, most of them within the granite where their margins are indeterminate ; they appear to be segregations rather than true veins. They are older than the quartz veins, and most, though not all of them, are apparently barren of cassiterite. Also prior to the quartz veins is a granitic variant in the form of a coarse granite-porphyry found in one locality. In addition to aplite, the granite is traversed by veins of tourmaline and quartz, the latter in many cases carrying tin and tungsten.

The workable cassiterite and wolfram veins, some 27 in number, are nearly vertical, strike for the most part N.N.E.-S.S.W., and occur in either the granite, the argillites, the slates, the fine sandstones or rarely the limestone, but have been found by Hobson to die out rapidly on meeting the limestone. The veins in the granite, with one exception, end upwards against the limestone which thus exists as a roof over most of the mine workings. In one case the vein has persisted into the overlying limestone but only for a short distance ; in other cases the veins pinch out as they approach the limestone and either end completely before reaching it or enter it for a short distance in the form of thin stringers. The limestone has in fact played an important economic role by preventing the dissipation of the mineral solutions and ensuring their concentration within short fissures. As a rule the walls of the veins are clean and sharp. The vein quartz is drusy and large vugs are occasionally seen lined with quartz crystals. No banding is observable in the veins, the disposition of the mineral contents being haphazard ; greisen along the veins is uncommon. Vein outcrops can occasionally be identified at the surface but in most cases their outcrops are hidden by surface deposits. In the clay slates and siltstones the vein system is very complex, and each individual vein is very thin.

The important veins vary from 2½ to about 5 feet in thickness. Amongst the minerals determined by Dunn from the veins are: cassiterite, wolfram, scheelite, pyrites, arsenopyrites, molybdenite, galena, sphalerite, chalcopyrite, bismuthinite, covellite, chalcocite, creussite and tungstite.[166] Sulphides, it will be seen, are quite common in the veins, and garnet—mostly a pale cinnamon-coloured grossularite—is not infrequent. Ore values tend to occur in definite shoots which are closely parallel to the granite periphery, the grade of the ore decreasing with depth. The genesis of the ores was obviously the last phase of the igneous processes and their deposition was very rapid. The periods of formation of the two chief minerals overlapped. Wolfram was the first of the two to form, but the deposition of cassiterite, when it did begin, took place rapidly; no stage was reached when the deposition of tin was unaccompanied by that of wolfram. The process of tourmalinisation was initiated prior to the formation of the quartz veins but also accompanied the latter. Hobson records the presence of a lead-zinc-silver mineralisation at Mawchi but not in economic amount.

The Tavoy Granite, with its mineral associations, has been recognised not only in Mergui, Amherst and Thaton, but also in the hilly eastern edges of the Yamethin and Kyaukse districts.

Yamethin.—The wolfram area of the Yamethin district lies close to the summit of peak Byingyi (6,254 feet) on the borders of the Yamethin district and Loilong, one of the Shan States.[167] It is of small extent but the veins are numerous and carry good values. The summit is formed of black calcareous grit, into which granite has intruded. The veins strike generally N. W.-S. E. and dip to the S.W., some of them at low angles; none of them is more than 15 inches across. They are all in the granite which is of the same type as that of Tavoy and Mergui. Beryl is common in the veins, an associate of wolfram which has not been recorded elsewhere. Molybdenite in small quantities is constantly found, especially in the higher-lying veins, and bismuthinite is occasionally found in traces, but cassiterite and the sulphide minerals have not been observed. The Yamethin veins in fact carry very few accessory minerals. Tourmaline, which is so common a mineral in the Mawchi veins, is absent, as it is in Tavoy,[168] except in certain younger pegmatites which are barren of cassiterite and wolfram. In the Yamethin district greisen is as commonly developed on each side of the quartz veins as it is in Tavoy and Mergui; in Mawchi, as already shewn, this feature is rare.

At Lebyin, between Kalaw and Pyinyaung, stibnite occurs in a quartz vein.[169]

Yawnghwe State.—Near the southern end of the Heho-Mawnang plain in the Southern Shan State of Yawnghwe Coggin Brown reports numerous dumps from old trenches and pits formerly worked

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[166] Rec. 73, 209-237 (1938).
[167] J. Coggin Brown & A. M. Heron, Rec. 50, 102 (1919).
[168] Hobson, Trans. Min. Geol. Inst. Ind. Vol. 37, 65 (1940).
[169] H. C. Jones, Rec. 53, 50 (1921).

for wolfram.[170] The latter mineral is found in thin plates and crystals irregularly distributed through thin quartz stringers and veinlets which intersect fine-grained siltstones of indefinite age. The old workings occur in a N.-S. zone a few hundred feet wide.

Yengan, Kyaukse and Meiktila.—In the State of Yengan and the districts of Kyaukse and Meiktila granites and porphyries play a prominent part. The granites, generally of the biotitic type, are often gneissic in the fine and the medium varieties. Locally they are porphyritic and with an increase of hornblende grade into hornblende granites. Basic segregations are occasionally seen in them. They are traversed by pegmatites and quartz veins, and in places by basic doleritic rocks. It is interesting to find in the same area volcanic tuff in small outcrops and consisting of angular and rounded fragments of quartz and felspar in a groundmass of quartz and sericite. The porphyries, which include both quartz and felspar bearing varieties, are found in lenses and rounded patches intrusive into the Coal Measures.[171]

In Yengan, one of the most northerly of the Southern Shan States, on the banks of the Panlaung river, 15 to 18 miles due east of Thedaw railway station, there are two main granite exposures separated by a series of hardened sedimentary rocks consisting chiefly of clay slates and white quartzites.[172] A compact grey limestone is also present but its relationship to the other sedimentaries is not known. Numerous quartz veins from a few inches to 3 feet wide and striking from E. N. E.-W. S. W. to N. E.-S. W., traverse both the granite and the clay slates and quartzites. The thinner veins often die out and become échelonned on one another ; close to the contact between the granite and the sedimentaries they contain wolfram, but become barren further away. The veins are said to be most productive when occpuying fissures at right angles to the major axis of intrusion ; in this they resemble the veins further south which show a similar tendency. As usual, distribution of the wolfram in the veins is irregular and patchy, and greisenisation is common where they traverse the granite. In one locality molybdenite occurs with the wolfram. Oxidised compounds of copper and iron in the upper portions of the veins appear to indicate the presence of sulphides below the zone of decomposition.

Wolfram is obtained in the Sabedaung Reserve Forest and in the Myittha township of the Kyaukse district. This occurrence marks the northerly limit of the tin and tungsten zone of Burma.[173]

Wolfram is reported from Mawnang State, in insignificant quantity.[174]

Antimony ore is found in the States of Mong Hsu (Naking and Loi Hke), Keng Tung (Mong Ing) and Mong Kung (Hkomhpok and

[170] Gen. Rep. Rec. 66, 81 (1932).

[171] Gen. Rep. Rec. 73, 70 (1938).

[172] J. Coggin Brown & A. M. Heron, Rec. 54, 236 (1922).

[173] J. Coggin Brown, Rec. 56, 99 (1924).

[174] J. Coggin Brown & A. M. Heron, Rec. 54, 236 (1922) ; J. Coggin Brown, Rec. 56, 99 (1924).

Loihsang). The ore is stibnite, mostly of the usual bladed, striated variety and often somewhat oxidised at the surface to valentinite and cervantite; the assays give between 30 to 40 per cent. of antimony. The country rock appears to be purple sandy shale, purplish white sandstone and limestone conglomerate which H. C. Jones refers provisionally to the Namyau series (Jurassic); in most cases Plateau Limestone is found in the immediate neighbourhood.[175] Some of the veins seems to lie in the Plateau Limestone itself.[176] The Naking deposits in 1908 yielded about 1,000 tons of stibnite, found irregularly distributed through a vein in the above-mentioned rocks. Some of the others appear to be quartz-stibnite veins in the Plateau Limestone.

The Wolfram and Cassiterite period.—The galena occurrences and the rare stibnite occurrences of Lower Burma would appear to be a late phase of the mineralisation which brought about the cassiterite and wolfram association. Coggin Brown remarks that evidence is not wanting that in some cases at least these and other sulphides, such as pyrrhotite and chalcopyrite, accompanied a reopening of the other vein fissures in which the tin oxide and the tungstate had already been formed; it is not certain, however, that this was always the case.[177] There are examples in which galena and antimonite occur alone in the veins. In some cases there is reason to believe that they occur in rocks similar to the Moulmein Limestone or to parts of the Plateau Limestone; they include the galena and cerussite deposits of the Pagah range in the Amherst district, and the lead and copper ores of the Yunzalin valley (Salween district).

Speaking generally of the wolfram-cassiterite mineralised zone, the southern portion is rich in tin ores while the northern has a larger proportion of wolfram and less tin.[178] This contrast is probably connected with the depth to which the batholith in question has been denuded. In Coggin Brown's opinion, the wolfram tends to occur at the higher levels, *i.e.*, at the top and sides of the domes, and the cassiterite lower down. "Thus the scarcity or absence of wolfram and hte relative abundance of the tin ore is an approximate measure of the extent to which the outer zones of the stocks concerned have been removed".[179]

The evidence affecting the question of the age of the Tavoy Granite, though somewhat more positive in character than that concerning the Tawng-Peng, is lacking in precision. The Tavoy is obviously much younger than the Tawng-Peng, in which there is a complete absence of stanniferous mineralisation. We may begin the consideration of the question by assuming that the tin-bearing intrusions from the Dutch East Indies up through Malaya and Siam into Burma all belong to one and the same period, *viz.*, the later phases of the Tavoy Granite. The latter is part of a batholith which is

[175] Rec. 53, 47 (1921).
[176] Gen. Rep. Rec. 33, 92 (1906).
[177] Rec. 56, 100 (1924).
[178] Mem. 55, 43 (1930).
[179] J. Coggin Brown; private communication.

probably continuous beneath the surface from the Southern Shan States, through Tavoy, Mergui and British Malaya to Sumatra, the islands of Sinkep, Banka, Billiton[180] and Borneo, and the Dutch East Indies; in Sumatra[181] and Borneo it carries no tin.[182] The facts bearing on the time of this intrusion and mineralisation have been marshalled by Coggin Brown and his able conspectus has been utilised to the full in the following summary.

In the first place, there are some grounds for believing that the granite in Thaton is post-Permian or even younger than the Lower Trias. In Siam, along its frontier with the Malay States, Credner finds the Triassic sediments clearly affected by limited metamorphism through folding and granitic intrusions, which must have taken place subsequent to the Triassic period; according to the same authority the determinate folding in Siam is intimately connected with the granitic intrusions, a point already brought out by Brown and Heron in the case of Tenasserim. In Mergui, the only evidence with regard to the age of the granite, besides its intrusion into the Mergui series, is seen in the Red sandstone series whose conglomerate pebbles have been derived from the granite. It is incontestable that the Red Beds of Mergui represent erosional derivatives of the granite and rocks which surround it. These Red Beds are the most westerly representatives of the Indosinas of the French geologists, those continental, sub-continental and lagoonal formations, of any age from Westphalian (Middle Carboniferous) or Stephanian (Upper Carboniferous) to Tertiary, which cover such an enormous area in Siam, Indo China and China proper. Coggin Brown is inclined to place the Burmese beds in the uppermost of the three divisions of the Indosinas, rather than in the middle or lower. This would make them not older than the Rhætic and in his opinion, probably not younger than Cretaceous. A Cretaceous age is favoured by the Dutch geologists, since the granites in Borneo are believed to have affected rocks of Jurassic age, and supplied pebbles to the overlying Cenomanian conglomerate. The same age has been accepted by Scrivenor with regard to the granite of Malay, which is composed of large orthoclase phenocrysts, up to 1½ inches in length, lying in a granitic matrix or base consisting of quartz, orthoclase, microcline, soda-plagioclase, biotite, muscovite, hornblende, rarely pyroxene and tourmaline, and a large variety of accessories including sphene (sometimes abundant), zircon, apatite, anatase, topaz, fluorite, cassiterite (rare traces), ilmenite, magnetite, pyrrhotite, pyrite and arsenopyrite and, in a few cases, cordierite and sillimanite; the aplitic veins, which are abundant in the granite and the surrounding stratified rocks, often carry cassiterite. Chhibber has recently put forward the suggestion that the granites now being considered are the acid complements of the late Cretaceous or early Tertiary serpentines of Burma, but there is no actual evidence for the conclusion. From relationships to rocks of somewhat indefinite age on

[180] Verbeek thought the granite of Billiton to be carboniferous (scrivenor).
[181] In Sumatra there is evidence of a granite older than the late palaeozoic.
[182] Gen. Rep. Rec. 60. 80 (1927). *See* also H. W. Turner. Econom. Geol. 14, 630 (1919).

Patit Island, Dudley Stamp has also suggested a late Mesozoic age for the granite.[183]

Incidentally, the wolfram deposits in the Dharwar rocks at Kalamati (Tatanagar) in Singhbhum, at Agargaon in the Nagpur district, and near Degana on the Jodhpur-Bikaner Railway, all belong to the Archæan era and are associated with one or other of the Archæan granites. The same is true of the cassiterite deposits found at Hosainpura in Palanpur State, Bombay, and at four localities in the Archæan terrane of Hazaribagh. In the case of wolfram and cassiterite, therefore, there were two epochs of mineralisation, just as there were in the case of the chromite deposits associated with the serpentines and peridotities. In both cases the two epochs were (i) the Archæan, and (ii) probably late Cretaceous or early Tertiary.

It is now generally agreed that the compression which produced the Indo-Malayan mountain system formed part of a widespread disturbance, the chief tectonic effect of which was the upheaval of the Himalaya. Suess, La Touche and others have long ago suggested that the Indo-Malayan movement took place somewhat earlier than the Himalayan and, so far as the severer phases of the latter are concerned, this may be true, but there seems to be no valid objection to the view that the uprising of the Himalaya was spread over a protracted interval covering more than one geological period. There is some evidence to show that the Himalayas were initiated at least before the close of the Lower Eocene epoch, and the suggestion has already been made in this work that the compression from the north which affected the coal basins of the Peninsula towards the close of Gondwana times, may have been the beginning of the Himalayan movement. Whether the Indo-Malayan section of the disturbance was spread over an equally spacious interval is a matter on which one can only surmise. It is at any rate permissible to conclude that the E.-W. compression in Burma was incomparably less intense and less concentrated than that which piled up the Himalaya. Brown and Heron remark that in the granite of the Tavoy district there are few indications of earth stress such as it would presumably exhibit if it had shared as a solid rock in the compressional movement which uplifted the Indo-Malayan mountain chain, and suggest that it was probably intruded towards the end of the period of the folding and accompanied the upheaval.[184] This idea can be made to fit the suggestion of a late Cretaceous or early Tertiary age for the granite by supposing that, while in the Himalaya earth movement was intense and perhaps at its maximum as late as the Upper Miocene epoch, the bulk of the compression in Burma had expended itself before the end of the Cretaceous, or else that this compression was never sufficiently intense to cause widespread and uniform metamorphism. This is pure hypothesis, however, and must stand or fall by future discoveries.

[183] Quart. Journ. Geol. Min. Met. Soc. Ind. 1, 17-22 (1926).
[184] Mem. 44, 194 (1923).

Comparison of the Burmese granites with those of the Himalaya.—The analogy between the granite intrusions of the Himalaya and Burma, concerning which the evidence is entirely independent, is striking. In both regions there are two principal intrusions, the older dating from some epoch in the middle of the upper half of the Palæozoic era (Carboniferous), and the other from perhaps the Upper Cretaceous or more generally the early Tertiary. In both regions the earlier rock is for the most part a simple biotite granite, showing signs of either crushing or foliation, while the latter intrusion is pre-eminently a tourmaline-bearing rock either in itself or in its end-products.

It is a curious fact that in Burma the older granite appears to be more or less confined to the northern half of the country, while the younger predominates in the south almost to the exclusion of the older rock. Each granite is associated with a mineralisation phase, the older with the deposition of lead, zinc and silver ores, the younger with ores of tungsten, tin and antimony. The two granites appear to overlap each other in Yamethin, where both are found. Further work on these little known rocks may necessitate a modification of the general statement but, so far as available evidence goes, there is ample justification for concluding that the older granite, with its particular form of mineralisation, predominates in the north, while the younger rock, with its accompanying wolfram and tin deposits, prevails almost exclusively in the south. Well away to the east, in French Indo-China it is to what the French geologists call the "Anthracolithique inferieur" that most of the granite massifs belong. Some of the Sumatran granite is thought to be older than late Palæozoic, while in the Malay States fragments of granite in tuff known to be older than the Mesozoic granite, as well as the presence of granite and tourmaline pebbles in the Triassic conglomerate, indicate the existence of a Palæozoic granite not yet found *in situ*. Incidentally, it is the older and not the younger of the Burmese granites which in its tin and tungsten associations corresponds to the tin-bearing and tungsten-bearing granites which characterised what Du Toit calls the Devono-Carboniferous orogeny in other parts of Gondwanaland, such as the tin granites of Australia. The latter as well as the Tawng-Peng Granite of Burma belong to the second of the three dominant metallogenic periods noted in the southern hemisphere.[185]

The presence of granites older than the Tavoy Granite within or in the immediate vicinity of the Tavoy and Mergui districts is proved by the discovery of granite fragments in the volcanic agglomerates of the Mergui series. These granites, which must of course have preceded the deposition of the Merguis, have so far not been recognised *in situ*. In the Tavoy district these granite fragments are described as about 3 inches in diameter, rounded, and very few in number.[186]

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[185] "Our Wandering Continents", 66-67 (1937).
[186] J. Coggin Brown & A. M. Heron, Mem. 44, 182 (1923).

In Mergui, pebbles of a biotite-hornblende granite have been found by S. R. Rau in a conglomerate interbedded with argillites belonging to the Mergui series on the east coast of Lampi Island. The pebbles include quartz and quartzite as well as granite and range from one to twelve inches across, the quartzite pebbles being somewhat larger than those of the granite.[187] In neither Tavoy nor Mergui could these granite pebbles have come from any considerable distance.

In Siam Credner reports the occurrence of infrequent granite pebbles in dark shales which are penetrated by quartz veins belonging to the main younger Tavoy Granite. Evidence of a pre-Carboniferous granite is said to exist in Malaya and the Dutch East Indies,[188] ant we have seen that such is present in the basal Jaunsar conglomerates of the Himalaya.

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[187] S. S. Rama Rau, Mem. 55, 11 (1930).
[188] H. L. Chhibber's "Geology of Burma", 523 (1934).

CHAPTER XXIX

TERTIARY—PALAEOCEN AND EOCENE.

Absence of marked and universal hiatus in deposition. 1. **Palæocene and Eocene of India and the Tibetan border: A. Western India:** (i) PALÆOCENE: (a) **Sind:** Distribution and subdivision; Lower Ranikot; Upper Ranikot; Doubtful beds east of the Rann of Cutch. (b) **Cutch.** (c) **Baluchistan:** Southern Waziristan. (d) **North-west Frontier:** Northern Waziristan; Kohat; The Samana Range: Thai. Age and relationship of the Ranikot. (ii) LOWER EOCENE: General character of the Laki series; Western Sind; Northern Baluchistan; Hindubagh, zhob valley; Southern Baluchistan; The Sulaiman Range; Throughout the Sulaiman foothills: Waziristan; Cutch; Kathiawar and Baroda. (iii) MIDDLE AND UPPER EOCENE: Distribution and subdivision; Sind and Baluchistan; (a) **Lower Kirthar:** General character and distribution; Chagai; Makran; The Sulaiman Range. (b) **Middle and Upper Kirthar:** Distribution; Sind and Baluchistan; The Sulaiman Range; Cutch and Kathiawar; Waziristan; Surat, Broach and Rajpipla. B. **Northwest India:** Eocene of Tirah: The Eocene of Rajputana. THE PALÆOCENE AND EOCENE OF KOHAT. General considerations, The Kohat salt fields; The vicinity of Kohat town; Bahadur Khel; Sections in the Northwest corner of the district; Panoba; Bannu. THE PALÆOCENE AND EOCENE OF THE PUNJAB AND HAZARA: Relationships; The Kala Chitta Hills; Peshawar; Hazara; The Potwar Plateau; The Salt Range; The Trans-Indus continuation of the Salt Range. The Eocene of Kashmir and Hundas: Chitral. C. **The Himalaya From the Simla Hills to Garhwal:** The Subathu Series; The Salt deposits of Mandi; Tectonic "inliers". D. **Tibet:** Everest Area. E. **Assam and the Coromondal coast:** Assam: The Disang Series of Assam; Pondichery. II. **Palæocene and Eocene of Burma:** Distribution; The Arakan coast: Salses; The Irrawaddy and Chindwin valleys. (i) **The northern part of the Arakan yoma and its contribution:** Mode of occurrence; PALÆOCENE AND LOWER EOCENEH The Laungshe Series; MIDDLE EOCENE: The Tilin sandstones: The Tabyin clay; UPPER EOCENE. Mode of occurrence; Pondaung stage; Yaw stage. (ii) **The southern Arakan Yoma:** Thayetmyo; (iii) **The Negrais group of the Arakan Yoma:** The Andaman and Nicobar Islands; Hukawng Valley. III. **Geographical relationships.**

Absence of marked and universal hiatus in deposition.—As between the Palæozoic and Mesozoic, so also between the Mesozoic and Cainozoic, there is no reason to conclude that the rock succession in every part of India shows a considerable hiatus. The lowest marine Tertiary beds in Sind are regarded, on the evidence of their fossils as the possible equivalents of the Landenian, and overlie a fresh-water stage; the latter is underlain with no visible discordance by one or two flows of the Deccan Trap, and all three formations are folded together anticlinally. The traps, varying in total thickness from 40 to 90 feet, rest upon the *Cardita beaumonti* beds of Upper Danian (Montian) age. The stratigraphical break between the Deccan Trap and the basal fresh-water Tertiaries need not, therefore, be more than that consequent on the change from sub-aerial volcanic to fluviatile conditions, and no more significant than that between a trap flow and any superjacent Inter-Trappean sediment. The one or two trap flows and the 1,500 feet of fresh-water sediments, therefore, occupy a stratigraphical position between the Upper Danian below and strata of probably Landenian age above. Even the marine stage overlying the fresh-water beds maintains strong Cretaceous affinities,

especially among its echinoids[1], though in other ways it shows some abrupt changes, as it does in other parts of the world.

This approximate continuity is carried through the Tertiary period into Recent times. By this it is not meant that there is in any one section a complete and conformable sequence. The sections indeed are all imperfect, and unconformable breaks are found in all, but the unconformity in one is in most cases bridged by continuous deposition in another, and there is no long and universal break at any particular time. Locally, the stratigraphical breaks are of considerable size and importance. In some cases, as for example in Sind, where orogenic disturbance has been too slight to affect the regularity of the structure, there is a parallelism of stratification which is so close that discontinuity of deposition has in the past been overlooked even between beds of widely different age. In this province the Nari (Stampian) rests in one place on the Kirthar (Lutetian), in another on the Laki (Ypresian) in each case with no visible discordance. In the Hab river section the Lower Kirthar is followed by the Upper Nari and the plane of division is so difficult to detect, owing to the fact that both these Tertiary stages have taken on a flysch facies, that the succession was at first described as a transition from one to the other[2]. A flysch facies of the Eocene as well as of the Oligocene is prevalent in southern Persia, where also volcanic activity was rife in early Eocene times. In Baluchistan, where the strata have suffered greater disturbance, unconformable breaks are often conspicuous, and are especially noticeable at the upper limit of the Eocene, during the Middle Miocene, and in the Pliocene; at these three points there is well marked erosional unconformity.

Tertiary deposits in the Peninsular region of India are extremely limited in distribution and restricted to the Narbada delta area, the immediate neighbourhood of the Coromandel coast, the eastern extremity of the Raniganj coalfield, and the southern borders of the Shillong Plateau of Assam. In the extra-Peninsular region they attain an immense development, both as regards their thickness and the area they cover. Taken as a whole, and ignoring local breaks in the continuity of diposition, they form a great system whose lower portion is, for the most part at any rate, a marine formation, while the upper consists of fresh-water, sub-aerial deposits. The distinction is not absolute, nor can the line of demarcation between the two types be everywhere drawn along the same horizon, yet the distinction is a real one of some importance. Everywhere, from Sind on the west to Burma on the east, the Eocene deposits are, generally speaking, marine and the Pliocene fresh-water or sub-aerial and, wherever the presence of intermediate formation makes the succession more or less continuous, there is a gradual transition from one type to the other.

[1] Pal. Ind. Ser. 7 & 14, Vol. 1. 99 (1871).

[2] R. Vredenburg, Rec. 34, 181 (1906).

THE PALAEOCENE—

Europe		*Sind*	*Baluchistan*	*Kohat*	
Ludian					
Bartonian			Mula Pass beds		
Auversian		Upper Kirthar		Sirki Shale (local)	
Lutetian		Middle Kirthar	Spintangi limestone	Yellow lime tones	Alveolina limestone
				Grey limestones	
				Nummulite shale	Red Clay Zone
				Kohat shales	
		Lower Kirthar		Clay-zone(7)	Gypsum and Salt
				Clay-zone(6)	
				Clay-zone(5)	
	Laki series	Laki limestone	Ghazij Shales	Yellowish limestone-zone(4)	
				Shekhan lime-stone-zone(3)	
		Meting shales		Clay-zone(2)	
Ypresian (Londinian)		Meting Limestone (Basal Laterite)	Dunghan Limestone	Clay-zone(1)	
Landedian		Upper Ranikot		Upper Limestone Breccia	
				Clays, shales & limestones	
Thanetian				Lockhart Hangu lime stone Breccia	
		Lower Ranikot		Hangu Shale and Sandstone	
Modtian					

— EOCENE OF INDIA

	The Potwar	*The Salt Range*	*Tibet*	*The Himalaya*		*Assam*
Upper Nummulitic				Subathu series		
					Jaintia series	Kopili stage
	Chharat series	Chharat beds (thin & local)		Mandi salt deposits		Sylhet Limestone
Lower Nummulitic	Hill Limestones	—gap—	Alveolina Limestone			Cherra Sandstone
		Bhadrar stage	Shales & flaggy sandstones			
		Sakesar Limestone	Orbitolina Limestone			
		Nammal stage				
		Patala shales	Spondylus shales			
		Khairabad Limestone	Operculina limestone			
			Gastropod limestone			
		Dhak Pass beds	Ferruginous sandstone			

The Palæocene and Eocene will be considered under the following headings:

I. PALAEOCENE AND EOCENE OF INDIA AND THE TIBETAN BORDER.

A. *Western India.*

(i) Palaeocene.

(ii) Lower Eocene.

(iii) Middle and Upper Eocene.

B. *Northwest India.*

C. *The Himalaya from the Simla Hills to Garhwal.*

D. *Tibet.*

E. *Eastern Assam and the Coromandel coast.*

II. PALAEOCENE AND EOCENE OF BURMA.

III. GEOGRAPHICAL RELATIONSHIPS.

The table on pp. 1474-75 shows the distribution of the various subdivisions of the Palaeocene and Eocene in India and Tibet.

I. PALAEOCENE AND EOCENE OF INDIA AND THE TIBETAN BORDER.

A. WESTERN INDIA.

The succession in western India is classified as follows:

		Maximum thickness.	
Kirthar series	Upper;	? 3,000 feet	Auversian
	Middle, Lower	4,000 ,,	Lutetian.
Laki series	Laki Limestone, Meting Shales, Meting Limestone, Basal Laterite	1,600 ,,	Ypresian.
Ranikot series	Upper	1,000 ,,	Sparnacian.
	Lower	1,500 ,,	Thanetian (perhaps ranging down into the Montian).

(i) PALAEOCENE.

The Palaeocene, often somewhat loosely spoken of in India as the Ranikot, and comparable for the most part to the Landenian (Thanetian and Sparnacian), has been recognised not only in Sind and the Baluchistan frontier, but also in Kohat (Samana and Thal), Waziristan, the Punjab (Salt Range), Attock, Western Persia, Tibet (Kampa Dzong and Tuna), Burma (Yeshin), Java (Djokja) and Borneo (Mangkalehat peninsula). The Libyan formation of north Africa is believed to extend down into the Palaeocene; the latter series is also probably present between Timbuktu and Lake Chad, in Somaliland (Allahkajid Limestone, with Ranikot echinoids[3]) in the vicinity of Baghdad and in Palestine. The presence on the Oman coast of Arabia of *Styracoteuthis orientalis* Crick, a very characteristic cephalopod of the uppermost Ranikot, suggests the presence in that region of beds of corresponding age.[4]

(*a*) SIND.

Distribution and Subdivision.—The Ranikot series of Sind is divisible into a lower fluviatile stage, usually from 1,000 to 1,200 feet thick but reaching a maximum of 1,500 feet, and an upper marine stage, usually from 700 to 800 feet thick but rising to a maximum of about 1,000 feet.[5] In the largest outcrop of the formation, which is the Band Vero tract northwest of Kotri, both the lower and upper stages are exposed and these are followed by the Alveolina or Laki limestone, the highest member of the Lower Eocene. The dip here is low and only the uppermost layers of the Lower Ranikot are visible. In a general way this inner core is surrounded by concentric belts of the various subdivisions of the Upper Ranikot and finally by an amphitheatre of low scarps of Laki limestone.[6] It is, however, only the lower zones of the upper Ranikot stage whose outcrops constitute continuous rings, for in the northern part of the dome the higher zones are affected by the overlap of the Laki beds; a full development of the uppermost zone is only visible in the southern portion of the dome.

In the long narrow outcrop including Ranikot Fort in the Laki range to the north of the Band Vero dome the Lower Ranikot is best exposed, but the only member of the Upper stage—seen at Barra Hill and at Jakhmari—is a thin brown calcareous sandstone containng *Calyptraphorus*[7] *indicus*: this is followed by the Laki Limestone. At Ranikot itself, at many other points in the Laki range and in the small inlier west of Ranikot, the Laki Limestone rests

[3] Monogr. Geol. Deptt. Hunter Mus., Glasgow Univ., No. 1, pt. 5, 46-78 (1925).

[4] E. Vredenburg Pal. Ind., New Ser., Vol. 3, pt. 1, p. 19 (1909).

[5] W.L.F. Nuttall, Rec. 65, 306 (1931).

[6] E. Vredenburg, Pal. Ind., New Ser., Vol. 3, Mem. 1, 8 (1909).

[7] Mis-spelt *Calyptrophorus* in the Palaeontologia Indica and elsewhere.

directly upon Lower Ranikot sediments, a result of an erosional unconformity and overlap. In the twin outcrops near Jhirak, south of Kotri, only the upper stage is visible.

The Laki range is occupied by an asymmetrical anticline with a very steep easterly limb, the deflected axis of the fold having been fractured by overthrust throughout most of the middle portion of the range. It is in the eastern scrap of the latter that the Lower Ranikot is exposed from Jakhmari to Ranikot. The base of the series is only seen in the Laki range and in the very small outcrop to the west thereof, and invariably rests upon a basaltic flow belonging to the Deccan Trap.[8]

Lower Ranikot.—The lower divisian of the Ranikot, which is about twice as thick as the upper, consists of soft sandstones, shales and clays often richly coloured and variegated with brown and red tints. Gypsum is of frequent occurrence. Some of the shales are highly carbonaceous and occasionally sufficiently pyritous to be used in the manufacture of alum. In one instance a lenticular bed of impure pyritous coal or lignite extends for about a hundred yards, swelling to a maximum thickness of 6 feet. The Lower Ranikot beds have yielded a few fragments of bone, and some dicotyledonous leaves; it was probably from this lower division that the calcareous algae. *Triploporella ranikotensis* Walt. was collected.[9] The Lower Ranikot beds have the appearance of being fresh-water, probably fluviatile deposits.

Under Jakhmari peak near the northern extremity of the Laki range exposure, and in the inlier west of Ranikot, there intervenes between the basalt and the fluviatile strata a thin oyster bank of littoral conglomerate which is not observed at Ranikot itself and many other places. It denotes a brief lapse to estuarine conditions after the continental phase represented by the basalt and before the fluviatile conditions of the Lower Ranikot. The large oyster of this horizon has been named by Mr. Vredenburg *Ostraea talpur* and is described as recalling in the shape and disposition of the cardinal region *O. gryphoides* Schloth. and *O. longirostris* Lam. of the Miocene and Oligocene.[10]

Upper Ranikot.—The river sediments of the Lower pass up into the marine strata of the Upper Ranikot, which in Sind occupy an area of something less than 200 square miles. Along the greater part of the Laki range in the north of Sind, the Laki series rests unconformably on the Lower Ranikot. Traced southwards in Sind, Dr. W. F. L. Nuttall found that Upper Ranikot beds make their

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[8] In 1906, Vredenburg speaks of the Ranikot as resting "with complete unconformity upon the Deccan Trap of the associated Cardita beaumonti beds (Rec. 34, 86 (1906), but in 1909 he states that "wherever the base of the series is visible, it is observed resting on a bed of basalt belonging to the Deccan Trap series." (Pal. Ind., New Ser., Vol. 3, Mem. 1, 7 (1909); the latter agrees with Blanford's statement [Mem. 17, 36 (1880)].

[9] J Walton, Rec., 56, 213 (1924).

[10] E. Vredenburg, Pal Ind., New Ser., Vol. 10, Mem. 4, 75 (1928).

appearance at the unconformable contact, horizons underlying the base of the Laki becoming progressively younger.[11] They are completely exposed in the south of the Band Vero dome and consist of numerous bands of dark brown limestone crowded with marine fossils and interstratified with sandstones, shales and clays which are frequently gypseous or ferruginous and sometimes saline. The uppermost horizons have the paler tints of the overlying Laki, a resemblance which has caused some confusion in fossil collecting.

The lowest horizon on the Upper Ranikot (Vredenburg's "Zone 1") is characterised by the gastropod, *Calyptraphorus indicus*, and is devoid of foraminifera; this gastropod has been noted also at a higher horizon where, however, it is rare. Above the basal horizon foraminifera, represented largely by alveolines and operculines are, abundant throughout. In the higher horizons true nummulites make their first appearance comprising radiate forms only; the first to be found is a minute assilina *Assilina ranikotensis* which, in the uppermost beds, is accompanied by *Nummulites nuttalli* and other species.

Dr. Nuttall divides the Upper Ranikot into two sub-stages, each approximately 500 feet thick, as follows:

(B) Beds with *Nummulites nuttali, N. guettardi. (Miscellania) miscella, Assilina ranikotensis,*[12] *Operculina canalifera* (*Nummulites sindensis* of Col. L. M. Davies) alveolines and abundant echinoids, corals and molluscs.

(A) Beds with abundant *Operculina hardiei* and the frequent occurrence at the base of *Calyptraphorus indicus.*

From sub-stage (A), which includes Vredenburg's Zones, 1, 2 and 3[13], have been obtained the following:

FORAMINIFERA.

Assilina ranikotensis Nutt. (an abundant microspheric form; Vredenburg's *A. miscella.*[14]

Operculina hardiei d'Arch. & Haime (common).

ECHINOIDEA (excluding forms erroneously attributed to the Ranikot).[15]

(2) *Cidaris* spines,
(2) *Phyllacanthus ranikoti* Dunc. & Sladen,
(3) *Phyllacanthus* spines,
(2) *Acanthechinus nodulosus* D. & S.,
(2 & 3) *Dictyopleurus haimei* D. & S.,
(3) *Dictyopleurus d'Archiaci* D. & S.,
(2) *Progonechinus eocenicus* D. & S. (provenance uncertain),
(3) *Conoclypeus declivis* D. & S. (a single, much broken specimen),
(2) *Phylliclypeus* sp.,
(3) *Plesiolampas placenta* D. & S. (genus confined to the Ranikot in India),

[11] Rec. 65, 307 (1931).

[12] Col. Davies is of opinion that more than one true species has been included under this name, one of them being his *Assilina subspinosa.*

[13] Dr. Nuttall found it difficult to recognise the stratigraphical limits of Vredenburg's four zones.

[14] Geol. Mag. 63, 112-121 (1926).

[15] Pal. Ind., New Ser., Vol. 3, Mem. 1, 15 (1909).

(3) *Plesiolampas praelonga* D. & S.,
(3) *Plesiolampas ovalis* D. & S.,
(2 & 3) *Eolampas antecursor* D. & S.,
(1, 2 & 3) *Echinanthus enormis* D. & S.,
(2 & 3) *Eurhodia morrisi* d'Arch. & H., var. D. & S. (genus confined to the Ranikot in India),
(2) *Paralampas pileus* D. & S.,
(2) *Paralampas minor* D. & S.,
(2) *Neocatopygus rotundus* D. & S.,
(2 & 3) *Hemiaster elongatus* D. & S.,
(3) *Linthia indica* D. & S.,
(3) *Schizaster alveolatus* D. & S.

ANTHOZOA[16].

(2) *Trochocyathus corbicula* Dunc.,
(3) *Placocyathus striatus* Dunc. (the only representation of this West Indian genus in the Indian Tertiaries),
(2) *Blagrovia simplex* Dunc.,
(3) *Astrocoenia (Platastrocoenia) ranikoti* (Dunc.),
(2) *Montlivaltia granti* d'Arch. & Haime,
(2) *Montlivaltia lyniani* Dunc.,
(3) *Montlivaltia ranikoti* Dunc.,
(2) *Feddenia typica* Dunc.,
(3) *Feddenia cristata* Dunc.,
(2) *Feddenia elongata* Dunc.,
(2) *Plocophyllia flabellata* Reuss. (An European form),
(3) *Leptoria hydnophoroidea* Dunc.,
(2) *Astrocoenia blanfordi* Dunc.,
(3) *Turbinoseris ranikoti* Dunc.,
(2) *Turbinoseris epithecata* Dunc.,
(2) *Turbinoseris haimei* Dunc.,
(2) *Turbinoseris indica* Dunc.,
(2) *Cyclolites alpina* d'Orb.,
(2) *Cyclolites ranikoti* Dunc.,
(3) *Cyclolites crenulata* Dunc.,
(2) *Cyclolites vicaryi* Haime,
(2) *Cyclolites superba* Dunc.,
(2) *Cyclolites haimei* Dunc.,
(3) *Stephanophylla indica* Dunc.,
(1) *Litharaea grandis* Dunc., (closely allied to the Indian Cretaceous *L. epithecata* Dunc.),
(3) *Porites superposita* Dunc.

BRACHIOPODA.

(3) *Terebratula hollandi* Cossm. & Piss.

LAMELLIBRANCHIATA.

(3) *Ostraea* cf. *multicostata* Desh.,
(3) *Ostraea grandicardinalis* Vred.,
(3) *Ostraea aschersoni* Mayer-Eymer,
(3) *Ostraea* ("*bellovacensis*"),
(3) *Ostraea (Flemingostraea) pharaonum* Oppenh., var. *aviculina* Mayer-Eymer (A variety found in the Libyan stage of Egypt),
(?2) *Ostraea (Flemingostraea) haydeni* C. & P.,
(3) *Ostraea (Flemingostraea) kalhora* Vred. (very common),
(1) *Ostraea (Flemingostraea) heteroclita* Defr. (Paris Eocene),
(3) *Spondylus alexandriae* Vred. (probably identical with *S. rouaulti* d'Arch. & H.)[17],

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[16] Pal. Ind., Ser 7 & 14, Vol. 1, pt. 2 (1880).
[17] Trans. Roy. Soc. Ed., Vol. 57, 67 (1931).

(1) *Cardita (Venericardia) semi-inflata* C. & P.,
Crassatella longicauda C. & P. (a loose specimen),
(1) *Meretrix morgani* C. & P.,
(2) *Corbula (Bicorbula) vredenburgi* C. & P.,
(1, 2 & 3) *Corbula (Agina) harpa* d'Arch. & H.,
(3) *Teredo intestinoides* C. & P.,
(3) *Lucina (Pseudomiltha) vredenburgi* C. & P.[18]

GASTROPODA.[19]

(2) *Tornatellaea vredenburgi* C. & P. (?=*T. bella* Conr. Clark & Martin, from Maryland).
(2) *Surcula polycesta* (*Bayan*) (=*Pleurotoma (Eopleurotoma ?) (amphibola* C. & P.),
(1) *Surcula (Apiotoma) vredenburgi* C. & P.,
(2) *Pleurotoma (Eopleurotoma) adela* (C. & P.) (=*Drillia adela* C. & P.),
(2) *Clavilithes leilanensis* Vred.,
(3) *Harpa (Eocithara) morgani* C. & P.,
(3, ?1 & 2) *Athleta (Volutocorbis) eugeniae* Vred.,
(1) *Athleta (Volutocorbis) victoriae* Vred.,
(1) *Athleta (Volutocorbis) burtoni* Vred.,
(3) *Athleta (Volutospina) isabellae* Vred.,
(2 & 3) *Athleta (Neoathleta) noetlingi* C. & P.,
(1) *Athleta blanfordi* Vred.,
(2 & 3) *Aulica sismondai* (d'Arch.),
(3) *Aulica (Aulicina) haimei* (d'Arch.),
(2) *Mitra (Cancilla) brachyspira* C. & P.,
(2) *Streptochetus* ? sp.,
(2) *Lathyrus* ? sp.,
(1) *Strepsidura cossmanni* Vred.,
(2) *Eutritonium (Sassia) sindiense* C. & P.,
(3) *Cassidaria archiaei* C. & P.,
(1) *Semicassis phillipsi* d'Arch. & H.,
(1) *Cassis (Eocasmaria) gradifera* (C. & H.),
(1) *Pyrula* ? sp.,
(2) *Eocypraea leilanensis* Vred. (recalls *E. newboldi*),
(2) *Cyproedia (Cypraeoglobina) feddeni* Vred.,
(2 & 3) *Gisortia tuberculosa* Duclos.,
(1) *Gisortia jhirakensis* Vred.,
(2) *Rostellaria (Amplogladius) morgani* C. & P.,
(1) *Calyptraphorus indicus* C. & P.,
(2) *Rimella prestwichi* d'Arch. & H.,
(3) *Terebellum distortum* d'Arch. & H.,
(3) *Terebellum (Mauryna) plicatum* d'Arch. & H.,
(3) *Pterocera? dimorphospira* C. & P. (=*Chenopus*) (*Maussenetia*) *dimorphospira* C. & R.,
(2 & 3) *Cerithium (Campanile) subsemicostatum* d'Arch. & H.,
(2 & 3) *Cerithium Cypraea (Rhinoclavis) angystoma* (d'Arch. & H.),
(2) *Cerithium pissaroi* Vred.,
(?2) *Turritella infrarimata* C. & P.,
(1, 2 & 4) *Turritella ranikot* Vred.
(3) *Cerithium* var. *halanensis* Vred.,
(1 & 2) *Cerithium hollandi* C. & P.,
(1) *Cerithium diastropha* C. & P.,
(2 & 3) *Mesalia mecquenemi* C. & P.,
(2) *Pleurocera varians* C. & P.,
(2) *Keilostoma (Paryphostoma) convexiusculum* C. & P.,
(2) *Keilostoma ? mesaliaeforme* C. & P.,

[18] Trans. Roy. Soc. Ed., Vol. 57 (1931).
[19] Pal. Ind., New Ser., Vol. 3, No. 1 (1909); Rec. 54, 243 (1922); Rec. 55, 52 (1923).

(?) *Hipponyx archiaci* C. & P.,
(1) *Natica (Naticina) hollandi* C. & P.,
(1) *Natica (Naticina) ampulliniformis* C. & P.,
(3) *Ampullina (crommeum ?) dolium* d'Arch. & H. (=*Mamilla ? bulloides* C. & P.),
(2 & 3) *Ampullina aulacospira* C. & P.,
(2) *Ampullina (Crommium) rouaulti* d'Arch. & H.,
(3) *Ampullina (Crommium) polybathra* C. & P.,
(3) *Scala (Acrilla) colpophora* C. & P.,
(2 & 3) *Velates perversus (Gmel)* var. C. & P. (abundant[20]),
(3) *Velates noorpoorensis* (d'Arch. & H.) (=*haliotis* d'Arch. & H.),
(2) *Tiburnus (Dillwynella) aulacochilus* C. & P.

CEPHALOPODA.[21]

(1, 2 & 3) *Nautilus deluci* d'Arch. (horizon not certain),
(1) *Nautilus cossmanni* Vred.,
(2 or 3) *Nautilus sindiensis* Vred.

In Nuttall's sub-stage B, corresponding to Vrendenburg's Zone 4 *plus* an upward extension of 120 feet, the following have been found:

FORAMINIFERA.[22]

Nummmulites nuttalli Dav. (microspheric: frequent; originally identified as *N. planulatus* Lam.),
Nummulites guettardi d'Arch. (megalospheric: common),
Siderolites (Miscellanea) miscella d'Arch. & H. (megalospheric: frequent),
Assilina ranikotensis Nutt. (microspheric; abundant; originally known as *Assilina miscella*),
Operculina hardei d'Arch. & H.,
Operculina canalifera d'Arch. (Microspheric; frequent; *O. sindensis* of Davies),
Lockhartia haimei (Dav.) (entirely confined to the Ranikot, and the first species of *Lockhartia* to appear and disappear),
Lockhartia conditi (Nutt.) (microspheric; rare; the most highly specialised form of *Lockhartia*),
Alveolina vredenburgi Dav.,
Alveolina (Flosculina) globosa (Leym.) (megalospheric; very abundant in the Lower Laki, ..
Assilina subspinosa Dav. (included by Nuttall in *A. ranikotensis*),
Discocyclina sp.

ECHINOIDEA.[23]

Cidaris verneuili d'Arch.,
Phyllacanthus sindensis D. & S.,
Salenia blanfordi D. & S. (*S. persica* Clegg, from the Persian Gulf is very similar)[24],
Cyphosoma abnormale D. & S.,
Dictyopleurus ziczac D. & S.,
Arachniopleurus reticulatus D. & S. (perhaps a variety of this species),
Eurypneustes grandis D. & S.,
Aeolopneustes de Lorioli D. & S.,
Conoclypeus sindensis D & S.,

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[20] According to Vredenburg *V. affinis* [d'Arch. & H.] but recognised by Cox; *see* Trans. Roy. Soc. Ed., Vol. 57, 28 (1934).
[21] Pal. Ind., New Ser., Vol. 10, Mem. 4 (1928).
[22] Rec. 65. 306 (1931).
[23] Pal. Ind., New Ser., Vol. 3, Mem. 1, 15 (1909).
[24] Pal. Ind., New Ser., Vol. 22, No. 1, 4 (1933).

Plesiolampas placenta D. & S.,
Plesiolampas ovalis D. & S.,
Plesiolampas rostrata D. & S.,
Plesiolampas polygonalis D. & S.,
Cassidulus ellipticus D. & S.,
Eurhodia morrisii d'Arch. & H., and var.,
Hemiaster elongatus D. & S.

ANTHOZOA.[25]

Trochosmilia medlicotti Dunc.,
Stylina reusai Dunc.,
Stylina cellulata (Dunc.) (="*astrocomia cellulata* Dunc."),
Stylocoenia maxima Dunc.,
Stylocoenia vicaryi Haime,
Plocophyllia sindiana Dunc.,
Diploria flexuosissima d'Arch. (Upper Eocene of Italy; Libyan of Egypt),
Stephanocoenia microtuberculata Dunc.,
Astrocoenia blanfordi Dunc.,
Astrocoenia nana Reuss,
Astrocoenia gibbosa Dunc.,
Astrocoenia ramosa (Sow.),
Thamnostraea (Isastraea) punctata (Dunc.),
Astraea morloti Reuss,
Prionastraea indica Dunc.,
Reussastraea grandis Dunc.,
Pachyseris murchisoni M. Ed. & J. Haime (Lutetian of Europe),
Trochoseris difformis Reuss,
Cyathoseris orientalis Dunc.,
Elliptoseris aperta Dunc.,
Turbinoseris elegans Dunc.,
Cyclolites ranikoti Dunc., var.,
Cyclolites anomala Dunc.,
Cyclolites altavillensis Defr. (Eocene of France),
Cyclolites striata Dunc.,
Thamnastraea balli Dunc.

LAMELLIBRANCHIATA.[26]

Ostraea grandicardinalis Vred. (horizon uncertain),
Ostraea (Flemingostraea) kalhora Vred,
Spondylus roxanae Vred. (probably the equivalent of *Sp. rouaulti* d'Arch. & H.)[27],
Arca (Barbatia) insignis Douv.,
Nucula archiaci C. & P.,
Cardita (Venericardia) hollandi C. & P.,
Cardita mutabilis d'Arch. & H.; a variable species including *Venericardia depressa* (d'Arch. & H.),
Crassatella (Pseuderiphyla) blanfordi C. & P. (Horizon not certain),
Cardium sharpei d' Arch. & H.[28],
Corbula capsuloides C. & P. (Horizon not certain),
Corbula (Agina) harpa d'Arch. & H. (abundant).

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[25] *Aplophyllia (Rhabdophillia) barkii* (Dunc.), from the Barki watercourse in the Laki range, was omitted from Vredenburg's list (Gregory. Pal. Ind., New Ser., Vol. 15, pt. 7 (1930)

[26] Pal. Ind., New Ser., Vol. 10, Mem. 2 (1927) and Mem. 4 (1928).

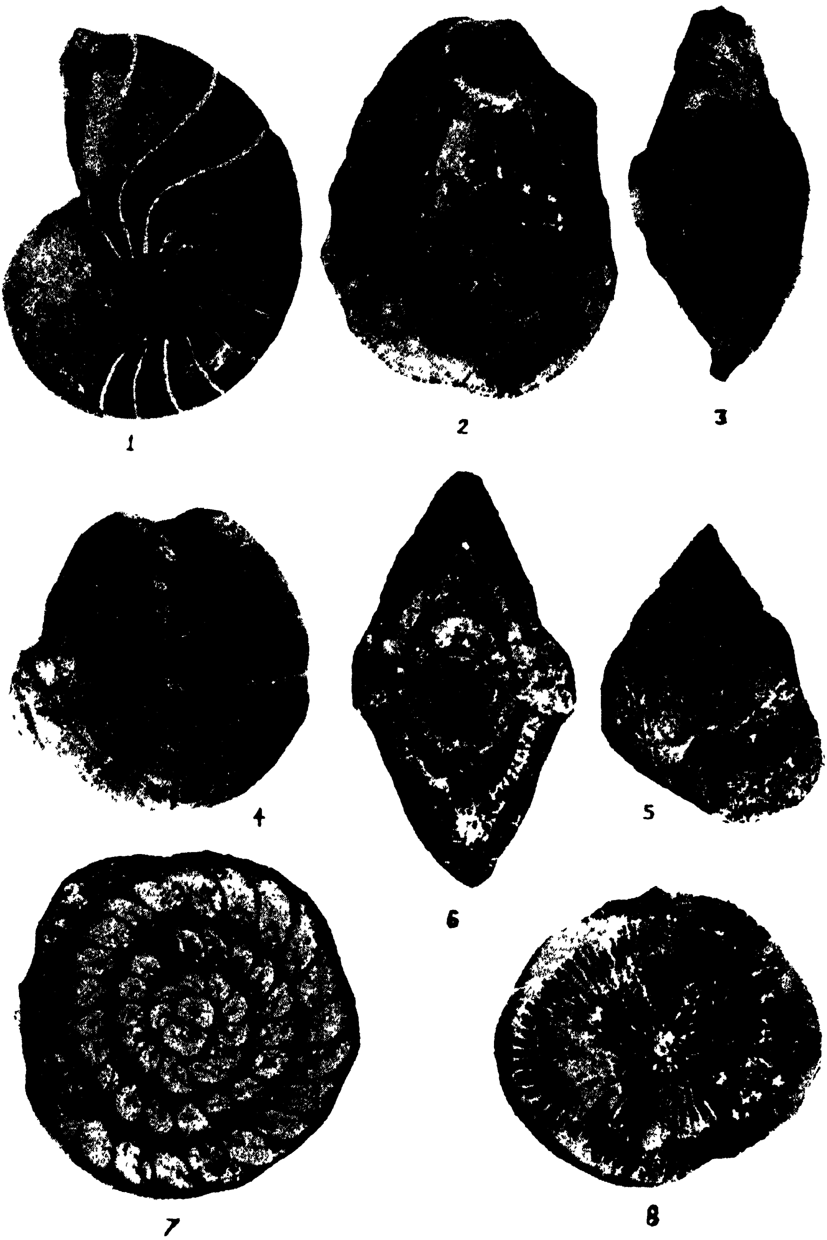
[27] Trans. Roy. Soc. Ed. Vol. 57, 70 (1931).

[28] *Cardium picteti* d'Arch. & H., said to come from the Eocene of Sind is preserved in a coarse sandstone identical with that containing *Venus subsglaurae* d'Arch. & H. which comes from the Miocene (Dr. L. R. Cox, Trans. Roy, Soc. Ed., Vol. 57, 83 (1931). *Cardium picteti* is nonetheless recorded from the Eocene (Kirthar) of Waziristan (see page 1519).

GASTROPODA.[30]

Bulla apicialis C. & P.,
Akera [*Acera*] *strepta* C. & P.,
Surcula blagravei Vred. (Cossman & Pissaro's *S. voyseyi*),
Surcula indica C. & P.,
Surcula (*Ancistrosyrinx*) *terebralis* Lam, var. *hypermeces* C. & P.,
Pleurotoma (*Genota*) *aspera* (Edw.), (=*Pleurotoma dictyophora*) C. & P.,
Pleurotoma (*Hemipleurotoma*) *eucallista* C. & P.,
Pleurotoma (*Eupleurotoma*) *jhirakensis* C. & P.,
Pleurotoma (*Eupleurotoma*) *pottingeri* Vred. (=*Drillia jhirakensis*) C. & P.,
Melongena (*Pugilina*) *muriciformis* (C. P.),
Pleurotoma (*Cryptoconus*) *perliratus* C. & P.,
Conus blagravei Vred. (Cossman & Pissaro's (*C. brevis*),
Conus subbrevis d'Arch. & H.,
Ancilla (*Alacospira*) *inopinata* C. & P.,
Olivella hollandi C. & P.,
Olivella vredenburgi C. & P.,
Athleta (*Neoathleta*) *noetlingi* (C. & P.), (=*Volutospina noetlingi*) C. & P.,
Athleta blanfordi Vred.,
Athleta (*Volutocorbis*) *eugeniae* Vred.,
Eovasum haimei (d'Arch.),
Aulica (*Aulicina*) *haimei* (d'Arch.) (very close to the Egyptian *E. frequens* Mayer-Eymar),
Volutoconus funiculifer C. & P.,
Volutoconus ? *corrugatus* C. & P.,
Volutilithes jhirakensis C. & P.,
Lyria cossmanni Vred.,
Lyria feddeni Vred.,
Murex sindiensis Vred.,
Fusus ? *jhirakensis* C. & P.,
Fusus (*Pagodula*) *colpophorus* C. & P.,
Strepsidura indica C. & P.,
Euryochetus nassaeformis C. & P.,
Pyrula pissaroi Cott.,
Eutritonium (*Sassia*) *permutabile* C. & P.,
Cassidaria carinata Lam.? (=*C. archiaci* C. & P. non Noetl.),
Cassidaria archiaci C. & P. non Noetl.,
Gisortia tuberculosa Ducl.,
Gisortia jhirakensis Vred.,
Calyptraphorus indicus C. & P. (rare),
Calyptraphorus hollandi C. & P.,
Rimella prestwichi d'Arch. & H.,
Rimella (*Drepanochilus*) *fusoides* (d'Arch.),
Rimella hollandi C. & P.,
Terebellum distortum d' Arch. & H.,
Terebellum (*Mauryna*) *plicatum* d'Arch. & H.,
Rostellaria (*Semiterebellum*) *lanceolatum* (C. & P.),
Chenopus (*Maussenetia*) *dimorphospira* C. & P.,
Cypraea (*Bernaya*) *angystoma* (Desh. ?),
Turritella halaensis Cossm.,
Turritella ranikoti Vred.,
Turritella hollandi C. & P.,
Mesalia mecquenemi C. & P.,
Solarium vredenburgi C. & P.,
Vanikoro (*Narica*) *subsphaerica* (C. & P.),
Cepatia ? *obliquistria* C. & P.,
Natica (*Naticina*) *subbrongniarti* Vred.,
Natica (*Naticina*) *subbrongniarti* Vred.,
Natica (*Naticina*) *adela* (C. & P.),

[30] Pal. Ind., New Ser., Vol. 3, Mem. 1, 5 (1909).



PALAEOCENE & EOCENE FOSSILS (A)

1. *Nautilus subfleuriausianus* d'Arch. (X1/2). 2. *Ostraea talpur* Vred. (X1/2). 3. *Calyptrophorus* Coss. & Piss. (X1). 4. *Schizaster alveolatus* Dunc. & Slad. (X1). 5. *Ampullina polybathra* Coss & (X1). 6. *Miscellanea miscella* d'Arch. & Haime (X22-1/2). 7. *Miscellanea miscella* d'Arc Haime (X22-1/2). 8. *Nummulites nuttalli* Davies (X4).

G. S. I., Ca

PALAEOCENE & EOCENE FOSSILS (B)

1. *Gisortia murchisoni* d'Arch. (X1). 2. *Natica adela* Coss. & Piss. (X1). 3. *Belosepia incurvata* Coss. & Piss. (X2). 4. *Montlivaltia granti* d'Arch & Haime (X1). 5. *Rimella fusoides* d'Arch. (X2). 6. *Dictyoconoides cooki* Carter (X10) 7. *Assilina granulosa* d'Arch. (X4). 8. *Assilina granulosa* d'Arch. (X10).

G. S. I., Calcutta.

Sigaretus ochetophorus C. & P.,
Ampullina aulacospira C. & P.,
Ampullina cf. *sigaretina* Lam.,
Ampullina (Crommium) pervicina C. & P. (perhaps identical with ***A. rouaulti***),
Ampullina (Crommium) rouaulti d'Arch. & H.,
Ampullospira constricta C. & P.,
Ampullospira (Euspirocrommium) cossmanni Vred. (found in the Eocene of Palestine; Middle Eocene of Jamaica),
Epitonium Scala (Crisposcala) tenuilamella Desh.,
Velates perversus (Gmel.) var., *noetlingi* C. & P. (According to Vredenburg, the equivalent of *V. affinis* (d'Arch. & H.) but recognised by Cox),
Turbo (Pareuchelus) adelus C & P.,
Clanculus euomphalides (d'Arch. & H.),
Liotia? (*Liotina*) *imperforata* C. & P. (accepted by Cox but thought by Vrendenburg to be the equivalent of *L. coultardi* (d'Arch. & H.),
Delphinula cordieri d'Arch.,
Fissurella feddeni C. & P.,
Vermetus (Serpulorbis) ranikoti Vred.

SCAPHOPODA.

Dentalium vredenburgi C. & P.,

CEPHALOPODA.

Belosepia incurvata C. & P.,
Styracotheutis orientalis Crick, (found in the Eocene of Oman),
Nautilus deluci d'Arch.,
Nautilus suofleuriausianus d'Arch. (horizon not quite certain),
Nautilus (Paraturia) spathi Vred.,

Doubtful beds east of the Rann of Cutch.—Around the foot of the granite hills of Nagar Parkar, and at other localities on the eastern margin of the Rann of Cutch, are beds of calcareous sandstone which to the west of Radhanpur are intercalated with limestone. These beds are supposed by Dr. P. K. Ghosh to be Tertiary or Cretaceous.

(b) CUTCH.

The Tertiary rocks in the island of Cutch occupy a belt, varying in breadth from about four to twenty miles, between the alluvium near the coast and the older rocks in the interior of the country. Tertiary formations also fringe the Deccan Trap and Jurassic outcrops on the borders of the two openings by which the Rann of Cutch communicates with the sea east and west of the State, while patches of the same Tertiaries are found here and there on the shores of the Rann, not only in the main region of Cutch itself, but also around the detached hilly tracts or islands, Pachham, Khadir, etc., and in Wagad. The Deccan Trap lava flows, which appear to have covered the greater part, if not the whole, of the Mesozoic region, had been completely swept away from the surface and the underlying Jurassic rocks exposed and largely eroded in places, before the marine Tertiary beds were deposited. Along the southern border of the Trap area, however, there is no sign of this unconformity, the Tertiary beds resting with no visible discordance upon the trap flows.

The survey of Cutch requires revision in the light of later discoveries. Wynne's classification of the Tertiaries with the modifications was as follows[30]:

Upper Tertiary	200-500 feet.
(unconformity)	
Argillaceous group (fossiliferous).	800-1,200 feet. Gaj.
Arenaceous group	130 feet.
Nummulitic group	700 feet. (Laki and ?Kirthar)
Gypseous shales	50-160 ?Laki.
Local bituminous shales	50-100 ?Laki.
Sub-nummulitic	20-200. Lower Ranikot.

The so-called "Sub-nummulitic group", probably corresponds to the Lower Ranikot, though it was in the first place grouped by Wynne as part of the Deccan Trap volcanic succession. This observer suggests that some of the beds may have been originally volcanic ashes while others may even represent decomposed lava flows. The formation consists chiefly of soft argillaceous beds, purple or red mottled with white, of laterite of various kinds, and of coarse sandstones which are distinguished by the brilliancy of their colouring, the prevailing tints being white, red, lavender, purple and orange. There are also some shales with leaf impressions, carbonaceous layers and occasionally gypsum. The soft, mottled argillaceous beds are of sedimentary origin but probably composed of the detritus of volcanic rocks. Fossils are rare in the Sub-nummulitic group, which extends along the southern edge of the traps in Cutch, overlapping the volcanic rocks to the west, and resting upon the Mesozoic near Lakphat. The same group is represented in several small patches deposited upon Jurassic beds on the borders of the Rann, both on the mainland of Cutch and on some of the detached hills or islands. Nowhere is this group more than about 200 ft. thick; frequently it does not exceed 20 feet.

(c) BALUCHISTAN.

From Zrind, a locality in the Marri country of Baluchistan, about halfway between the Sind exposures and those of Thal, Colonel A. L. Duke collected specimens including such typical Ranikot forms as *Operculina sindensis, Miscellanea miscella* and *Discocyclina ranikotensis*. It is almost certain, therefore, that additional exposures of the Ranikot occur in this intermediate region.[31] Col. Davies has also identified Ranikot foraminifera in collections from the valley of Kelat, to the south of Zrind.[32]

The reported occurrence of the Ranikot in the Bolan Pass and Quetta valley by Griesbach is a mistake, the misidentified beds over-

[30] Mem. 9, 48 (1872).
[31] Col. Davies, Q.J.G.S., 83, 265, Note 1 (1927).
[32] Geol. Mag., 77, 253 (1940).

lying the Alveolina Limestone,[33] and belonging to the Ghazij shales.[34] The beds mapped as Ranikot in the Chagai district of Baluchistan are now regarded as Laki.

Southern Waziristan.—Fossil collections made by Mr. E. S. Pinfold and examined by Colonel Davies proved the extension of the Ranikot to the neighbourhood of Jandla and Kotakai in Southern Waziristan.[35]

The ostracod, *Bairdia subdeltoidea* has been found in the Spinkai scarp and the north of Kotakai; from the latter locality come also other ostracods *Cythereis bowerbanki* and *C. mersondaviesi* Lath.

(d) NORTH-WEST FRONTIER.

Northern Waziristan.—In North Waziristan the Ranikot is represented by shales with limestone bands, and in places attains a considerable development; some of the limestone bands have a rich coral fauna. The Ostracods, *Bairdia subdeltoidea* (Munst.), *Cythere ranikotiana* Lath. and *Cythereis bowerbanki* Jones, from a locality 12 miles south of Thal have been identified by Miss Latham; the *Bairdia* has also been found at two other localities, one about 9½ miles and the other about 15 miles south of Thal.[36]

Kohat.—The Sind and Cutch outcrops were the only known occurrences in India of the Palæocene or Ranikot until the important discoveries of Col. L. M. Davies who recognised this series first of all in the neighbourhood of Thal in the extreme west of Kohat, and afterwards in the Samana Range on the northern frontier of the same district, both localities being over 500 miles N.N.E. of the most northerly exposure of the same beds in Sind.

The Samana Range.—The Ranikot succession around Fort Lockhart in the Samana Range, halfway between the town of Kohat and Thal, and extending over the Orakzai border, overlies Cretaceous beds already noticed (p. 1296), and has been mapped and described in detail by Col. Davies.[37] The chief interest in the early Tertiary of this anticlinal range lies in the possession by some of the beds of a marine fauna which appears to be older than that of the Upper Ranikot of Sind, a fact which makes them the oldest marine Tertiary strata in Asia. The succession has been subdivided by Davies as follows:

(e) Upper Ranikot limestone breccia	30 ft.
(d) Upper Ranikot clays, shales and impure limestone bands	70 ft.
(c) Lockhart limestone; replaced in the southern foot-hills by the Hangu Breccia	200 ft.
(b) Hangu Shale	2—20 ft.
(a) Hangu Sandstone	140 ft.

[33] Mem., 18, 22 (1881).
[34] Rec. 34, 177, Note 1 (1906).
[35] C.R. Soc. Geol. de France, 17 July, 1937, 22-23.
[36] Proc. Roy. Soc. Ed., 59, pt. I, No. 4, 46 (1938).
[37] Pal. Ind. New Ser., Vol. 15, pt. 1, 9-13 (1930).

The Hangu Sandstone is a white unfossiliferous quartzitic sandstone like those of the Cretaceous succession below, and sometimes showing the same large rusty spots seen on one of the latter. It has been taken as the base of the Palæocene since it merges upwards into the overlying Hangu Shales, becoming so strongly calcareous as to be inseparable from the latter. Near Hangu its marly uppermost layers include small embedded subangular blocks of grey limestone.

The Hangu Shale is described as a band of yellowish clay, packed with well preserved fossils. Though locally squeezed out, it is a very constant horizon in spite of its small thickness. Cephalopods and the larger foraminifera, with the exception of *Lockhartia haimei*,[38] are absent, but the beds, according to Professor J. W. Gregory, include indications of a coral reef probably formed towards the lower limiting depth of coral-reef formation. The following fossils have been determined, the corals by Professor Gregory and the Mollusca by Dr. L. R. Cox.[39]

FORAMINIFERA.

Lockhartia haimei (Dav.)

ALCYONARIA.

Blagrovia simplex Dunc. (A Sind form),
Placotrochus tipperi Greg.,
Trochosmilia ? hastata Greg.,
Trochosmilia ? nadiai Greg.,
Euphyllia thalensis Greg,
Astrocoenia (Platastrocoenia) ranikoti (Dunc.),
Astrocoenia (Platastrocoenia) (? A Sind form),
Cyclolites vicaryi Haime, (A Sind form),
Cyclolites crenulata Dunc., (A Sind form),
Cyclolites striata Dunc., (A Sind form),
Cyclolitopsis pascoei Greg.

LAMELLIBRANCHIATA.

Ostraea sp.,
Cardium inaequiconvexum Cossm. & P. (A Sind form),
Cardita hanguensis Cox,
Meretrix indica Cox,
Trapezium daviesi Cox,
Crassatellites exiguus Cox,
Corbula samanaensis Cox,
Corbula (Bicorbula) praeefiarata Cox.

GASTROPODA.

Pirena torta Cox,
Bellardia (?) sp.,
Batillaria coronata Cox,
Cerithium (Campanile) brookmani Cox,
Pyrazus octogonus Cox,
Vermetus hanguensis Cox,
Turritella daviesi Cox,
Turritella (Haustator) noetlingi Douv. (=*T. lahirii* Cox); found in the *Cardita beaumonti* beds),

[38] Private Communication from Col. Davies.
[39] Pal. Ind., New Ser., Vol. 15, pts. 7 & 8, (1930).

Turritella ranikoti Vred., (A Sind form),
Turritella cf. *hollandi* Cossm. & P.,
Mesalia fasciata (Lam.), (Abundant; a form from the Paris Lutetian; probably the equivalent of *M. mecquenemi C. & P.* from the Sind Ranikot),
Mesalia pagoda Cox,
Tibia samanaensis Cox, (closely related to the Sind form, *Rostellaria (Anplogladius) morgani* Cossm. & P.),
Aporrhais (Lambis) goniophora (Bellardi), (A southern French from; probably identical with the Sind form, *Aporrhais dimorphospira* C. & P.),
Rostellarin (Terebelopsis; Semiterebellum) lanceolatum (C. & P.) (4, Sind form),
Rimella levis Cox,
Euspira roei Cox,
Globularia brevispira (Leym.) (Lower & Middle Lutetian of France),
Globularia (*s. lat.*) *sulcata* Cox,
Ampullospira (Euspirocrommium) conicum Cox,
Ampullina (Pachycrommium) indicum Cox, Very close to *Ampullina (Crommium) sindiensis C. & P., which* Vredenburg unites with *Crommium rouaulti* (d'Arch. & H.),
Ampullina (Crommium) rouaulti (d'Arch. & H.) (A Sind form),
Cypraea (Eocypraea) cotteri Cox,
Cypraea (Protocypraea) kohatica Cox,
Solarium (Architectonica) mainwaringi Cox,
Streptochetus foxi Cox,
Dolicholatirus indicus Cox,
Hemifusus (*s. lat.*) *montensis* Cox,
Eovasum (Aulicana) haimei (d'Arch.) (A Sind form),
Murex (Phyllonotus) wadiai Cox,
Murex (Phyllonotus) sandersoni Cox,
Strepsidura tipperi Cox,
Strepsidura scobina Cox,
Turricula (Pleurofusia) hanguensis Cox,
Turricula (Ancistrosyrinx) haydeni Cox,
Voluta vredenburgi Cox,
Athleta (Volutocorbis) daviesi Cox, (remarkably similar to the Indian Upper Cretaceous species *Voluta (Volutocorbis) radula* Sow.),
Athleta (Volutospina) wynnei Cox, (closely resembles the European Lower Eocene form, *Voluta elevata* Sow.),
Lyria samanaensis Cox, (very closely allied to the Sind form, *V. feddeni* Vred.) ...

SCAPHOPODA.

Dentalium hanguense Cox.

As we shall see, the Hangu Shales occur stratigraphically 200 feet below the equivalent of Zone 4 of the Upper Ranikot of Sind, accept ing *Nummulites nuttalli* as an index fosil of the latter. The Hangu Shales, therefore, belong either to lower horizon of the Upper Ranikot, or represent a marine phase of the Lower Ranikot. There is good reason to believe that a marine phase of the Lower Ranikot is present at Thal, a few miles west of the Samana outcrops, where also a limestone similar to the Lockhart Limestone occurs a considerable way below what is thought to be the base of the Upper Ranikot. With regard to the fauna, the mollusca include a number of species closely comparable with forms in the *Cardita beaumonti* beds, but only two identical, *Mesalia fasciata* and *Cardium inaequiconvexum*, the former of which is found throughout the Upper Ranikot. Cox

concludes that there are no forms in the Hangu Shales with undoubted Cretaceous affinities but that, on the other hand, 7 or 8 of the 48 species are identical or nearly so with forms from the Upper Ranikot of Sind and many others are closely related. Most of the 7 or 8 identical species have a considerable vertical range but their presence illustrates the Tertiary rather than Mesozoic proclivities of the fauna. If the Hangu Shales were the equivalent of any one of the Sind zones, there should be a much greater resemblance between the two in view of the comparative proximity of the two areas. Since they cannot be regarded as contemporaneous with any one of the Sind zones, the probabilities are, in the opinion of Dr. Cox, that they belong to a lower horizon, *i.e.*, to the Lower Ranikot.

The Lockhart Limestoe is grey in colour and full of the remains of small corals; microscopic sections show it to abound in *Lithothamnium* and small foraminifera. In places the basal 20 or 30 feet consist of a blue-black shaly type with ochreous weathered surfaces. The uppermost layers, which have survived denudation only behind Fort Lockhart where they are protected by overlying beds, are composed of a dark grey crystalline limestone packed with foraminifera and echinoid spines, with bands and lenticular intercalations of impure black chert containing a few fish teeth.

In the southern foot-hills, according to Col. Davies, this limestone is represented by a massive braccia full of sub-angular fragments of all sizes up to that of a man's head. The fragments, all of them consisting of limestone similar to that seen around the Fort, are loosely assembled in a lighter coloured matrix. This breccia not only occupies the same stratigraphical position as the Lockhart Limestone but occasionally assumes the aspect of this rock. The matrix is found to contain essentially the same foraminifera and *Lithothamnium* as the detrital portions of the bed, and is evidently of a primary nature. Over 100 feet of the breccia still remain but the original thickness must have been much greater. As we shall see, a small thickness of an exactly similar breccia has been noted in the Thal area, 35 miles west of Hangu village. Such brecciated limestones recur in places at the base of the Laki and Kirthar series where they have been observed to pass laterally into an ordinary conglomerate with pebbles of foreign rocks; they probably indicate shallow-water conditions and a certain degree of local discordance.[40]

It is in the basal portion of the Lockhart Limestone that foraminifera first make any notable appearance in the local sequence, including abundant *Miliolidae* and *Textulariidae; Rotalidae* are also represented and include the eminent Indian genus, *Lockhartia,* and minute forms of *Nonionina.* Col. Davies has determined the following:

FORAMINIFERA.

Lockhartia haimei Dav.,

[40] E. Vredenburg, Rec. 34, 178 (1906).

Lockhartia newboldi (d'Arch. & H.); (found in the middle and perhaps also Lower Eocene of Somaliland),

Lockhartia conditi Nutt., var. *roeae* Dav.,

Nonionina ?sp.

The absence of *Nummulites nuttalli,* a characteristic foraminifer of the uppermost Ranikot, and the restriction of *Lockhartia conditi* to the uppermost layers of the Lockhart limestone, seem to indicate a Lower Ranikot age for this stage, though its topmost layers may include the lower zones of the Upper Ranikot.[41]

In one pot only have beds higher than the Lockhart limestone survived and this is behind the Fort where a very small outcrop of clays, shales and bands of impure limestone, is made use of as a butt for musketry practice by the garrison. The limestones, which are fractured and contain abundant quartz grains, have yielded foraminifera and a few small molluscs, among the latter the Hangu Shales species, *Corbula samanaensis.* The *Lockhartia* and their small associates of the beds below have disappeared abruptly and given place to nummulites, operculines and occasional discocyclines. Foraminifera, however, are not abundant and all of them are of Upper Ranikot Sind forms. The presence of *Nummulites nuttalli* and *N. thalicus* (perhaps the megaspheric form of *N. nuttalli*) seems to indicate a high horizon in the Upper Ranikot, but the rich fauna of the Sind Zone 4 is not found. The thickness of this stage is about 70 feet. In adition to the two nummulites, Col. Davies identifies *Operculina* cf. *canalifera* d'Arch. and an indeterminable species of *Discocyclina Lithothamnium,* echinoid spines and molluscan fragments are the only other forms of life so far recorded.

The beds just mentioned are capped by 30 feet of a limestone breccia exactly similar to the Hangu Breccia, but containing operculines not seen in the latter, as well as nummulites of similar type to those found in the beds below. In this stage, which is the highest seen, the mollusca and most of the large foraminifera of the beds below have disappeared, while there is at the same time an abundant recurrence of the smaller foraminifera of the types found in the Lockhart Limestone, accompanied by occasional nummulitines. *Lithothamnium* occurs in the lower layers of this stage.

Thal.—The Ranikot stage has been again recognised by Col. Davies near the Fort of Thal at the western end of the Miranzai valley, in the extreme west of the Kohat district. Here the Jurassic and Cretaceous deposits of Kadamak Mountain, north of the Fort, are succeeded on the south side by Ranikot beds which also crop out in outliers on all sides of the Fort. After some repetition due to folding the Ranikot sediments are succeeded to the southeast of the Fort by a thin belt of Lower Laki beds which are surmounted by a

[41] L. M. Davies, Pal. Ind., New Ser., Vol. 15, pt. 6, 79 (1930).

thick scarp of Lower Siwalik. The Ranikot succession is described as follows.[42]

Upper.	5. Blue-grey clays, with some thin calcareous layers locally fossiliferous.	2 feet.
	4. Clays and subordinate limestones with *Nummulites nuttalli*.	50 feet.
	3. Clays with subordinate limestone bands containing *Astrocoenia blanfordi* Dunc. and other fossils in their lowest horizons.	Not less than 500 feet, perhaps considerably more.
Lower.	2. Dun-coloured sandstones, weathering black, with subordinate greenish and yellowish clay partings, both occasionally fossiliferous, with *Siderolites* (*Miscellanea*) *miscella*, *Alveolina oblonga* and *Ampullina* (*Crommium*) *pervicina*.	200 feet.
	(b) Hard, splintery, pink, green and purple calcareous shales with obscure plant impressions.	About 150 feet.
	(a) An inconstant band of brecciated limestone.	12-15 feet.

Mesozoics

The thin band of brecciated limestone which sometimes intervenes between the Mesozoic deposits below and the calcareous shales above is lithologically indistinguishable from the Hangu Breccia of the Samana range, the equivalent of the Lockhart limestone. In the dun-coloured sandstone stage are found turreted gastropods, *Pecten*-like lamellibranchs and large *Ostraeae*. Some of the gastropods resembled types seen in the lowest Samana stages while others are of Upper Ranikot aspect; the only species definitely identified is *Ampullina* (*Crommium*) *pervicina*, a mollusc found in the uppermost Ranikot of Sind. The small foraminifera mentioned above accompany the *Ostraeae* and abound in the upper portions of the stage. As to the age of the stage, the fossil evidence is inconclusive; Col. Davies prefers to reject a correlation with the brecciated limestone and to place the beds among the Lower Ranikot for the time being.

Stage 3, which is practically devoid of foraminifera, appears to be the equivalent of Zone 1 and possibly part of Zone 2 of the Sind sequence. North-east of the Fort, where the junction with the beds below is not seen, and the thickness may be considerably more than 500 feet, the bulk of the beds are unfossiliferous, but the lowest visible horizons have yielded *Semicassis phillipsi* d'Arch. & H. and *Turritella diastropha* Cossm. & P., both of the Zone 1 forms, together with *Mesalia mecquenemi* Cossm. & P., a species found in Zones 2, 3 and 4 of Sind and in the lowest Eocene deposits of Samana. The small

[42] L. M. Davies, Q.J.G.S., Vol. 83, 260-290 (1927).

outliers of this stage between Kadimak and Thal village are described as full of corals which, in the opinion of Prof. J. W. Gregory, grew as isolated discs, nodules or small tufts, probably on banks at depths of 200 feet or more ; the following have been identified.[43]

ACTINOZOA.

Astrocoenia blanfordi Dunc.,
Latimaeandra kurramensis Greg.,
Staminocoenia rudis (Dunc.),
Pseudastraea daviesi Greg.,

Stage 4 contains abundant *Nummulites nuttalli*, other foraminifera, a few indeterminable molluscs, and numerous small corals ; in the easterly exposures it is uniformly but locally succeeded by stage 5. The fauna of stage 4 is as follows:

FORAMINIFERA.[44]

Nummulites nuttalli, var. *kohaticus* Dav.,
Nummulites thalicus Dav.,
Nummulites thalicus, var. *gwynae* Dav.,
Nummulites globulus Leym., var. *indicus* Dav.,
Assilina ranikoti Nutt.,
Operculina cf. *canalifera* d'Arch.,
Operculinoides sindensis (Dav.),
Siderolites (Miscellanea) miscella (d'Arch. & H.),
Siderolites stampi (Dav.),
Lockhartia conditi (Nutt.),
Lockhartia newboldi (d'Arch. & H.).
Lockhartia haimei (Dav.), ..
Discocyclina ranikotensis Dav.,
Alveolina vredenburgi Dav.,
Lepidocyclina (Polylepidina) tibetica (Douv.)[45],
Lepidocylina (Polylepidina) punjabensis Dav. (a primitive form).

ALCYONARIA (Prof. J. W. Gregory).

Paracyathus altus Greg.,
Stylophora vaughani Greg.,
Feddenia jacquemonti (d'Arch. & H.), (found in the Gaj. of Sind),
Antillia octoformis Greg.,
Aplophyllia barkii (Dunc.), (Sind, but ? Ranikot),
Diploria flexuosissima (d' Arch.), (found in the Ranikot of Sind, zone 4),
Stylina duncani Greg.,
Stylina cellulata (Dunc.), (found in the Ranikot of Sind, Zone 4),
Astrocoenia gibbosa Dunc.,
Astrocoenia daviesi Greg..
Stephanocoenia tricoronata Greg.,
Trochoseris obliquatus Greg.,
Trochoseris daviesi Greg.,
Cyathoseris aff. *orientalis* Dunc., (found in the Ranikot of Sind, Zone 4),
Thamnastraea balli Dunc., (found in the Ranikot of Sind, Zone 4),
Thamnastraea punctata (Dunc.), (found in the Ranikot of Sind, Zone 4),
Thamnoseris piriformis Greg.,
Thecoseris circumvictus Greg., ..
Cyclolites crenulata Dunc., (Sind, Zone 3),
Cyclolites altavillensis Defr. (found in the Ranikot of Sind, Zone 4 of France),

[43] Pal. Ind., New Ser., Vol. 15, pt. 7, 83 (1930).
[44] L. M. Davies, Q.J.G.S., Vol. 83, 284 (1927).
[45] Col. L. M. Davies ; Private Communication.

Pachyseris murchisoni (d'Arch.) (found in the Ranikot of Sind, Zone 4),
Actinacis lata Greg.,
Goniaraea piriformis Greg.,
Isis ranikoti Greg.,

OSTRACODA.[46]

Bairdia subdeltoidea (Münst.),
Cythereis bowerbanki Jones,
Cythereis mersondaviesi Lath.

The corals indicate the same moderately shallow sea which characterised the previous stage. This stage may with some confidence be equated with the topmost subdivision in Sind (Vredenburg's Zone 4).

Age and relationships of the Ranikot.—Accepting the conclusions of Dr. Nuttall and Col. Davies that the Laki beds are Ypresian, the Upper Ranikot would fall into the Landenian, and the Lower Ranikot into the Montian or possibly Lower Landenian.[47]

It is interesting to find the Ranikot stage present in the western borders of Persia, where it is at least 500 feet in thickness and has yielded the following foraminifera identified by Col. Davies.[48]

Nummulites nuttalli Dav., *Siderolites (Miscellanea) stampi* (Dav.),
Nummulites thalicus Dav., *Siderolites (Miscellanea) miscella* (d'Arch. & H.),
Operculinoides cf. *sindiensis* (Dav.), *Sakesaria* cf. *cotteri* Dav., *Alveolina (Flosculina) globosa* Leym.

This succession is followed by beds probably of Laki age with *Alveolina lepidula* Schwag., *A.* cf. *oblonga d'Orb.*, and *Orbitolites* cf. *complanatus* Lam.

The Ranikot horizons of southern Tibet and Burma will be considered later; beds of probably the same age are recorded from Somaliland (Allahkajid limestone, with Ranikot echinoids),[49] from the vicinity of Baghdad, from Palestine, perhaps from Egypt (Lower Libyan) and from Borneo.[50] The presence on the Oman coast of Arabia of *Styracoteuthis orientalis* Crick, a very characteristic cephalopod of the uppermost Ranikot, suggests the presence in that region of the beds of corresponding age.[51]

(ii) LOWER EOCENE.

General character of the Laki series.—The Lower Eocene of western India, known as the Laki series, is present in Baluchistan and western Sind, and was originally regarded as a basal group of the Kirthar. A considerable number of the Ranikot foraminifera pass up into the Laki, but there is nonetheless a well marked palæontological distinction between the two series, and two new genera of

[46] Mary H. Latham, Proc. Roy. Soc. Ed., 59, pt. 1, No. 4, 46 (1938).
[47] L. R. Cox, Pal. Ind., New Ser., Vol. 15, pt. 8, 133-134 (1930); L. M. Davies. Trans. Min. Geol. Inst. Ind., Vol. 21, 314-321 (1927).
[48] 'Nature', Vol. 141, 202 (29th Jan., 1938).
[49] Mongor. Geol. Deptt. Huntur Mus. Glasgow Univ. No 1, pt. 5. 40-78.
[50] J. W. Gregory, Pal. Ind., New Ser., Vol. 15, pt. 7, 83 (1930).
[51] M. Casamann & G. Pissarro, Pal. Ind., New Ser., Vol. 3, pt. I, 39 (1909).

echinoids, *Amblypygus* and *Brissopsis,* as well as the molluscan genera, *Vicarya, Vicetia* and *Cordiopsis,* make their appearance. The echinoids of the Laki stage as a whole mark the intermediate stages in the change from the Regulares group of the Ranikot to the Irregulares group of the Kirthar, but there is not a single form common to the Ranikot and Laki stages.[52] From the Meting Limestone Nuttall records the foraminifera: While in lower Sind this series is com-

FORAMINIFERA.

Nummulites atacicus Leym. (a very common Indian foraminifera, ranging up into the lower part of the Middle Kirthar),
Nummulites mamilla Ficht & Moll? (perhaps a variety of *N. guettardi* d'Arch.),
Nummulites subatacicus Douv. (the megalospheric form of *N. atacicus*),
Assilina granulosa d'Arch. (including the megalospheric form, *A. leymieric* d'Arch.; both forms show a preference for argillaceous beds),
Alveolina oblonga d'Arch.,
Alveolina ovoidea d'Orb. (=*A. subpyrenaica* Leym.; very abundant, not uncommonly constituting the entire rock),
Alveolina (Flosculina) globosa Leym. (a widely distributed form),
Orbitolites coriplanati Lam. (well known species; ranging throughout the Laki and Kirthar),

In addition the Meting Limestone has yielded the following echinoids:—
Echinocyamus rotundus Dunc. & Sladen,
Eolampas excentrica D. & S.,
Echinolampas lepaodformis D. & S., (similar to *E. omanensis* Clegg from Oman),
Rhynchopygus calderi d'Arch. & H.
Rhynchopygus pugmeus D. & S., (Perhaps identical with *Rh. calderi*),
Brissopsis sufflatus D. & S.,
Metalia sowerbyi d'Arch.,
Metalia agariciformis D. & S.,

Nuttall records also species of *Ostraea, Velates schmideli Chemn.* (? *V. perversus*). *Nerita affinis* d'Arch., and *Nautilus* sp., and Vredenburg *Gisortia (Vicetia) metingensis.*[53]

posed mostly of limestone, shale predominates further north in parts of Baluchistan, though the lithological change does not appear to be accompanied by any noticeable variation in the foraminiferal fauna.[54] The beds are more disturbed in Baluchistan than they are in Sind. In Baluchistan and the Punjab the Laki is a coal-bearing series. The Laki series probably corresponds to the Upper Libyan of Egypt.

Western Sind.—The Laki in western Sind is exposed in anticlinal ridges of which the Laki, Sumbak, Surjana and Kara ranges are examples. It is well seen in the flat-topped hills of almost horizontal strata southwest of Hyderabad where it has been recently studied and described in detail by Dr. W. L. F. Nuttall.[55] Here the beds form

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[52] The Laki echinoid originally identified as *Arachniopleurus reticulatus* is either a variety of this Ranikot species or a different species altogether. (E. Vredenburg, Rec. 34, 185, Note 1 (1906)).
[53] Pal. Ind., New Ser., 7, Mem. 3, 31 (1927).
[54] W. L. F. Nuttall, Geol. Mag., 63, 496 (1926).
[55] Q.J.G.S., Vol. 81, 417-453 (1925).

an extremely flat anticlinal fold with a strike fault in its eastern flank. Resting unconformably upon the Ranikot, and succeeded unconformably by various higher members of the Tertiary system, the series has been subdivided by Nuttall as follows:

4. Laki Limestone	200—600 feet.
3. Meting Shales	95 „
2. Meting Limestone	140 „
1. Basal Laterite	25 „
	460—860 feet.

The Basal Laterite represents an old eroded land surface of Ranikot rocks and, like all such deposits, wanders from one stratigraphical level to another; it is in reality intermediate in age between the Ranikot and the Laki epochs, with a discordant junction along its upper as well as its lower limit. With regard to the latter, the hiatus between it and the underlying Ranikot increases at first northwards until in the Laki range the Laterite lies directly upon the Lower Ranikot; further to the north, beyond Sind, the gap decreases and apparently reaches a minimum in the Salt Range where later Ranikot and earlier Laki elements make their appearance. Southwards in Sind the stratigraphical discordance between the Ranikot and the Laki is less than it is elsewhere in this province, and thin impure limestones with *Assilina granulosa* are intercalated in the ferruginous beds of the Laterite. From a basal pisolite in Hyderabad comes the gastropod, *Fissurella hyderabadensis* Cox. This sub-stage comprises about 25 feet of highly ferruginous lateritic clay with concretions of iron oxide, sometimes expanding into ferruginous sandstones; these beds accumulated under terrestrial conditions, intervening between the two marine epochs of the Ranikot and the Meting Limestone. That the renewed invasion of the sea was from south to north is shown, as Nuttall points out, by a northward overlap; in the north, for instance, around Band Vero, the Laterite is immediately overlain by the Laki Limestone, while in the vicinity of Meting further south the Meting Shales and Meting Limestone intervene.

The Meting limestone, mistaken at one time for the Laki Limestone which it resembles lithologically, makes its appearance on the east side of the outcrop of Meting Shales. Its individuality was first recognised by Dr. Nuttall who described it as a massive, nodular, creamy white, alveoline limestone, much more fossiliferous than the Laki Limestone. Northwards this sub-stage dies out and is not found west of Kotri or in the Band Vero area; to the east and southeast of Meting village it is separated unconformably from the Upper Ranikot by the Basal Laterite. Two foraminifera *Flosculina globosa* and *Alveolina oblonga*, abundant in the Meting Limestone are also found in the Upper Ranikot where, however, they are relatively uncommon and dwarfed in development. The genus, Alveolina is, in fact, largely restricted to the Laki stage and evidently throve in a

clear sea. *Flosculina globosa* and a few echinoids have not been found above the horizon of the Meting Limestone, otherwise the fauna of the latter is not very different from that of the Laki Limestone, in spite of the terrestrial break represented by the Meting shales between the two epochs of marine deposition. From the Ranikot, on the other hand, both the Meting Limestone and Laki Limestone faunas are marked different.

The Meting Shales are described by Nuttall as comprising reddish brown lateritic clay, gypseous shales, and soft, thinly bedded, reddish brown, sandy limestones. In some of these impure ferruginous limestones small forms of *Assilina granulosa* are abundant. Both upper and lower boundaries of the Meting Shales are sharply defined and the Meting Limestone in the northern part of its outcrop shows definite signs of erosion previous to the accumulation of the shales. Except that they are partly littoral in character, the Meting Shales differ in no great extent from the Basal Laterite and mark another terrestrial phase, though of much shorter duration, intervening between the shallow sea epochs of the Meting Limestone and Laki Limestone. In the north, to the west of Kotri and Band Vero, the Meting Shales as well as the Meting Limestone are absent, and the Laki Limestone is separated from the underlying Upper Ranikot beds only by about 10 feet of very ferruginous laterite, the local equivalent of the Basal laterite and marking a maximum unconformity.

The Laki Limestone[56] forms a prominent scarp for over 30 miles along the western flank of the Laki range, where its thickness varies from 600 to 800 feet ; here it is mostly hard, white, massive or nodular, and often made up almost entirely of alveolines, especially of *A. subpyrenaioa, A. oblonga* and *Flosculina globosa*. This limestone occurs on both sides of the Band Vero plain, stretching northwards nearly as far as Manjhand and southwards past Meting to unite with the southward extension of the Laki hills outcrop ; to the west of the latter are one or two smaller outcrops. Near Meting this sub-stage consists of about 200 feet of massive, creamy-white or buff limestone, mostly chalky in texture but including hard layers which give rise to a series of terraces and scarps. The Laki limestone also forms low hills south of Hyderabad town on the east side of the Indus, and has been recognised in several hill ranges of the Thana Bula *taluk* in the Karachi district. The following fauna has been collected from the Laki Limestone, as described by Nuttall.

FORAMINIFERA.[57]

Nummulites atacicus Leym., (accompanied by the megalospheric form, *N. subatacicus*),
Nummulites mamilla Ficht. & Moll.,
Assilina granulosa d'Arch., (Abundant),

[56] The term "Alveolina Limestone" used by Griesbach, Vredenburg and others for the limestones of the Laki Stage is no longer suitable.

[57] Perhaps to the Laki limestone belongs a shaly limestone at Petiani, 10 miles west of Kotri, from which has been collected *Lockhartia tipperi* Dav.; *L. tipperi* has recently been found in the Palaeocene of Somaliland (L. M. Davies & E. S. Pinfold, Pal. Ind., New Ser., Vol. 24, No. 1, 48 (1937)).

Alveolina oblonga d'Orb.,
Alveolina subpyrenaica Leym., (very abundant),
Orbitolites complanata Lam.

ECHINOIDES.[58]

Leiocidaris canaliculata D. & S.,
Porocidaris anomala D. & S.,
Coptosoma macrostoma D. & S., (formerly *Cyphasoma macrostoma*), [59]
Micropsis venustula D. & S.,
Arachniopleurus recticulatus D. & S.,
Conoclypeus alveolatus D. & S.,
Echinocyamus nummuliticus D. & S.,
Echinocyamus nummuliticus var. *obesus*,
Echinocyamus nummuliticus var. *oviformis*,
Echinocyamus nummuliticus var. *planus*,
Amblypygus subrotundus D. & S.,
Eolampas excentrica D. & S.,
Echinolampas rotunda D. & S.,
Echinolampas subconica D. & S.,
Echinolampas obesa D. & S.,
Echinolampas nummulitica D. & S.,
Rhynchopygus calderi d'Arch. & H.,
Rhynchopygus pygmeus D. & S., (perhaps identical with *Rh. calderi*),
Hemiaster apicalis D. & S.,
Hemiaster nobilis D. & S.,
Hemiaster carinatus D. & S.,
Hemiaster digonus d'Arch.,
Metalia sowerbyi d'Arch.,
Metalia scutiformis d'Arch.,
Metalia scutiformis var., *rotunda* D. & S.,
Metalia depressa D. & S.,
Schizaster symmetricus D. & S.,
Prenaster oviformis D. & S. (abundant in the Laki Limestone of Sarawan, and found also in beds of the same age in the Persian Gulf.[60])

CEPHALOPODA.

The following mollusca from the Laki series of Sind, *i.e.*, including both the Meting and Laki limestones, have been determined by Dr. L. R. Cox:

Nautilus sp. (casts).

LAMELLIBRANCHIATA.

Nucula sindensis Cox,
Mytilus nummuliticus d'Arch. & H.,
Modiola subobtusa (d'Arch. & H.),
Modiola daviesi Cox,
Vulsella legumen d'Arch. & H.,
Vulsella legumen d'Arch. & H.,
Ostraea multicostata Desh.,

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[58] We may perhaps add three corals since they come from a Laki limestone locality, viz., *Trochocyathus nummuliticus* Dunc., and *Leptocyathus epithecata* Dunc., both from Gagar hill, east of Surjana, and *Astrocoenia numisma* Defr. from the Gagar *nala*, east of Surjana, N.E. of Bula Khan's Thana (P. M. Duncan, Pal. Ind., Ser. 7 & 14, Vol. 1, 59, 60 & 64 (1880).

[59] P. M. Duncan, Journ. Linn. Soc. (Zool.), 23, 1-311 (1889).

[60] E. L. G. Clegg, Pal. Ind., New Ser., Vol. 22, No. 1, 15 (1933).

Ostraea cossmanni Dolf. ("*O. plicata*" of Vredenburg).[61]
Gryphaea (*Pycnodonta*)*brongniarti* (Bronn) (stratigraphical provenance not certain; Middle Eocene to Aligocene of Europe; N. Africa, Asia Minor and Borneo) (the *Ostrea vesicularis* of many observers),
Ampullina (*Pachycrommium*) *flemingi* (d'Arch. & H.) (stratigraphical provenance not certain),
Cardita sindensis Cox.,
Cardita subcomplanata d'Arch. & H., (stratigraphical provenance not certain),
Cardita dufrenoyi d'Arch. & H., (stratigraphical provenance not certain),
Cardita ovoides d'Arch. & H., (stratigraphical provenance not certain),
Cardita funiculosa d'Arch. & H.,
Lucina metableta Cossm. (Egypt and Somaliland),
Lucina (*Loripinus*) *pharaonis* Bell. (N. Africa, S. Arabia), (including "*L. subvicaryi*", "*Corbis elliptica*" and "*C. subelliptica*"),
Lucina kohatica Cox (Somaliland),
Lucina (*Pseudomiltha*) *gigantea* Desh. (Europe, Asia Minor and N. Africa),
Diplodonta hindu Cox.
Diplodonta (?) *indica* Cox (stratigraphical provenance not certain).
Tellina subdonacialis d'Arch. & H., (stratigraphical provenance not certain),
Meretrix cf. *sulcataria* (*Desh.*) (="*Venus subovalis*" and "*Cybricardia carteri*"),
Meretrix cyrenoides (d'Arch. & H.),
Venus filifera d'Arch. & H.,
Blagraveia sindensis (d'Arch. & H.) (some from the Meting Limestone, Somaliland and Persia),
Blagraveia corrugata Cox, (Somaliland),
Cardium cotteri Cox,
Cardium halaense d'Arch. & H. (including *C. austeni*. Egypt),
Cardium salteri d'Arch. & H.,
Cardium horneri d'Arch. & H.,
Cardium (*Discors*) *bunburyi* d'Arch. & H., (Somaliland),
Chama brimonti d'Arch. & H. (some from the Meting Limestone (Somaliland),
Corbula (*Bicorbula*) *subexarata* d'Arch. & H. (Egypt and Samaliland),

GASTROPODA.

Turbo punjabensis d'Arch. & H.,
Velates perversus (Gmel.).
Cepatia cepacea (Lam.), (Europe),
Ampullina (*Crommium*) *subacutella* (d'Arch. & H.) (?=*Glubulus obtusus* Sow. from the Kirthar, and *Cr. willemeti* (Desh.) from the Paris Lutetian),
Ampullospira (*Euspirocrommium*) *oweni* (d'Arch. & H.) (Egypt, Asia Minor, Lower Miocene of Sumatra, Middle Eocene to Oligocene of S. Europe),
Ampullospira (*Euspirocrommium*) *cossmanni* (Vred.) (stratigraphical provenance not certain),
Hippochrenes cf. *amplus* (Sol.), (abundant; Lower Eocene to Oligocene of Europe; Middle Eocene of Egypt and Somaliland),
Terebellum cf. *fusiforme* Lam. (Europe),
Terebellum carcassense Leym. (S. Europe),
Terebellum subbelemnitoideum d'Arch. & H.,
Prestrombus rockei Cox,
Cyprdedia hyderabadensis Cox,
Protocypraea expansa (d'Arch. & H.),
Gisortia (*Vicetia*) *murchisoni*, (d'Arch. & H.), (Laki limestone),
Gisortia (*Vicetia*) *metingensis* (Vred.), (typical of the Meting beds),
Gisortia vredenburgi Schild (Laki limestone),
Oliva virginiae d'Arch. & H.,
Cymbium eocenicum Cox (probably Laki limestone),
Conus sp.,
Gosavia humberti (d'Arch. & H.),

[61] Gen. Rep. Rec. 41, 63 (1911).

Gosavia multidentata (d'Arch. & H.) equivalent to Vredenburg's "*Aulica multidentata*".

CRUSTACEA.

Neptunus sindensis Stol. (from "a yellowish nummulitic limestone, from the Lukkee Hills in Sind").[62]

Traces of petroleum were found in a shallow well 8 miles south of Rohri, and may indicate the presence below the surface of the Laki series, which is presumed to be the main oil-bearing formation of this part of India.[63] A boring, over 1,000 feet deep, at Sukkur, obtained only gas. The beds exposed in the neighbourhood belong to the upper Kirthar limestone, the outcrop stretching southwards for 50 miles. The beds encountered in the boring beneath this limestone comprised shales and clays of a very uniform character, with thin bands and nodules of hard, grey limestone.

Northern Baluchistan.—In Baluchistan, as already seen, the *Cardita beaumonti* stage of the Cretaceous is overlain in the Des valley of the northern parts by 100 feet of black unfossiliferous shales, and in Jhalawan further south by 300 feet of strata with unidentifiable fossils and interbedded tuffs and basalts. In both areas the next beds are limestones with fossils belonging to the Laki series. In the north the term Dunghan Limestone has been used for this limestone, and the Laki series of the Quetta neighbourhood, the Bolan Pass and Marri and Bugti Hills may be regarded as made up of:

(2) Ghazij Shales	3,000 feet
(1) Dunghan Limestone	2,000 feet

The confusion regarding the age and relationships of the Dunghan Limestone has recently been removed in a summary of the position by Mr. E. S. Pinfold[64]. This limestone group forms an easily recognisable horizon, constant over a wide area and found by Griesbach extending across the greater part of southwest Afghanistan into Khorassan. Southwards and south-eastwards from Quetta it becomes much reduced and in the Bolan Pass is only about 40-200 feet in thickness; E.S.E. wards also it thins out into the Marri and Bugti Hills, but for over 250 miles it forms an almost continuous outcrop from the Bolan Pass to the borders of Waziristan, where it disappears,

[62] F. Stoliczka, Pal. Ind., Ser. 7 & 14, No. 1, p. 7 (1871).

[63] T. H. D. La Touche, Rec. 28, 58 (1895).

[64] Rec. 74, 189-198 (1939): The greater part at least of Dunghan hill is made up of Cretaceous beds, and whether any portion of the Eocene is present in the exposure has been questioned (in L. M. Davies, Q.J.G.S., 96, 230 (1940) ¶. Even if any stage of the Laki is represented, the term, Dunghan limestone, appears to have been used originally to include Cretaceous horizons. The name, Dunghan, therefore, is not particularly fortunate, and "Bolan Limestone", as Colonel Davies suggests, would be a more appropriate designation for the group under consideration. At the same time, the term, Dunghan, has been used by Nuttall, Pinfold and others, including Colonel Davies himself, for a limestone of Lower Laki age in the Bolan Pass and other localities. This practice has been adopted in the present work. Further investigations, it is to be hoped, may justify the rejection of the name Dunghan altogether and its replacement by the term, Meting limestone.

in the opinion of Pinfold, probably as the result of an overlap along the junction of the Tertiaries with older rocks.

The Dunghan is a hard, compact, blue or dark grey, massive but well-bedded limestone, often brecciated especially at the top and bottom, varying in purity but with no notable bands of shale. It is occasionally nodular but is quite different from the soft, white, nodular limestone of the Laki series in Sind. In places it has been described as conglomeratic, especially when thin. West of Bibi Nani the dull purplish grey boulders of the conglomerate range up to a foot and more in diameter, lying in a yellowish grey and somewhat softer matrix ; both boulders and matrix, however, are full of foraminifera of the same species. In most places, according to Pinfold, the Dunghan stage includes one massive bed of limestone several hundred feet in thickness ; in the eastern parts of the Bugti Hills and in some other areas it is made up of two or more thin beds of limestone separated from each other by olive grey shales.

In the Bolan Pass the Dunghan limestone is described by Nuttall as resting unconformably on massive limestone and shale considered to be of Cretaceous age.[65] In the Mazar Drik anticline a thin representative of the Dunghan limestone is seen resting with no visible divergence of dip upon the *Cardita beaumonti* beds ; in spite of the absence of any angular unconformity, there is a hiatus between these two formations corresponding to the whole of the Ranikot series. In the upper Beji valley the base of the Dunghan is said to be a massive conglomerate, some of the fragmentary material of which was derived from the grey Jurassic limestone which forms the core of many of the local anticlines ; if this limestone has been correctly identified, there must have been considerable denudation before the Dunghan deposition began. Throughout the Kalat State, the Marri and Bugti Hills, and the Loralai district, the Dunghan Limestone is the lowest member of the Tertiary succession.[66]

Occurring as it does beneath the comparatively soft Ghazij Shales, Kirthar and Siwalik beds, the tough and resistant Dunghan Limestone is everywhere responsible for the summits and great dip slopes which flank all the higher hills. According to Pinfold, large sheets of the limestone are occasionally seen to have slid over subjacent shales and to have come to rest a considerable distance—sometimes extending to miles—from their normal position. The beds of the group are frequently traversed by the narrow gorges or *tangi* which in Baluchistan are such striking witnesses to the independence of hydrography and structure.

Traces of petroleum are widespread in the Dunghan group. Small quantities of thick oil have been obtained from shallow wells at Khattan near Sibi, where small seepages accompanied by sulphurous water had previously been observed.[67] Numerous indications of oil

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[65] Q.J.G.S., Vol. 81, 420 (1925).

[66] Nuttall, Q.J.G.S., Vol. 81, 420-421 (1925).

[67] R. D. Oldham, Rec. 23, 104 (1890); Rec. 26, 9 (1893).

have been noted along the Sind-Pishin railway, occurring mostly in the Dunghan Limestone but sometimes in the Ghazij Shales.[68]

With regard to fossils, foraminifera are everywhere abundant and calcareous algae frequently occur. A few other forms have been obtained from this limestone which has been correlated by Nuttall with the Meting Limestone on account of its fauna, and especially by reason of the included *Flosculina globosa*, a form which in Sind is almost restricted to the Meting Limestone, and found but rarely and usually in a dwarfed condition in the Upper Ranikot. Dr. Nuttall's list of foraminifera from the Dunghan Limestone includes:

Nummulites atacicus Leym.,
Nummulites irregularis Desh.,
Assilina granulosa d'Arch.,
Alveolina lepidula Schw.,
Alveolina subpyrenaica Leym.,
Alveolina (Flosculina) globosa Leym.,
Orbitolites complanata Lam.,
Opertorbitolites douvillei Nutt.

In the Sham plain fish remains have been found in a black shale immediately above the top of the limestone.

The Ghazij group is composed of a great thickness of grey and olivegreen, fissile shales, of varying degree of hardness and with a tendency to weather spheroidally. Subordinate beds of limestone occur near the top and some thin sandstones lower down; near Harnai and Shahrig (Shahrag) the upper part of the group is characterised by some bands of ferruginous sandstone. The shales contain numerous concretions which differ from the matrix merely in being more calcareous and not infrequently contain organic remains. Along the outcrop of this group, from Mach in the Bolan Pass to Harnai, coal seams, some of them 3 feet in thickness, are found near the top and near Harnai have proved of considerable importance in a country where fuel is so scarce. The coal seams have been found north of the Thal Chotiali plain and in the Luni Pathan country to the east, as well as in the localities above mentioned, in every case close to the western limit of the known exposures of the Ghazij group, a limit which is regarded as the original western limit of deposition in the country east of Quetta. Associated with the coal and sandstones are numerous shallow-water shells, many of them with the valves still united, and frequently forming beds of shell marl intimately related to the coal seams, both deposits witnessing probably to deltaic conditions of deposition. Near Shahrig the coal seams are more numerous but very thin; leaf impressions are abundant and nearly all parallel-veined. Owing to their soft nature the Ghazij Shales are much disturbed. They represent a facies of extremely limited extent and varying greatly in thickness; near Spintangi they are not far from 3,000 feet thick, at Shahrig they are considerably thicker, while

[68] Rec. 23, 105 (1890).

towards Khattan they cannot be more than 1,500 or 2,000 feet. The following foraminifera are recorded by W. L. F. Nuttall[69]

Nummulites atacicus Leym. (abundant),
Nummulites irregularis Desh.,
Assilina granulosa d'Arch. (very abundant),
Alveolina ovicula Nutt. (rare),
Discocyclina archiaci Schl., var. *baluchistanensis* Nutt. (rare).

The following mollusca from the Harnai district, and mostly from the lower part of the formation, have been identified by Dr. L. R. Cox.[70]

LAMELLIBRANCHIATA.

Mytilus (*Arcomytilus*) Sp.,
Ostraea (*Crassostraea*) cf. *soudanensis* Douv. (Sudan and ? Jamaica),
Ostraea multicostata Desh.,
Chlamys wynnei Cox (from Harnai; stratigraphical provenance unknown),
Cardita mutabilis d'Arch. & H.,
Meretrix cf. *villanovae* (Desh.) (Europe and Egypt).

GASTROPODA.

Amaurellina noetlingi Cox,
Cerithium ? *oldhami* Cox,
Cerithium (*Vicarya*) *eocenica* Cox, (Very similar to the Upper Eocene and Oligocene European form, *Potamides* (*Tympanotomus*) *vivarii* Oppenh., especially the variety, *alpina*; also to a form the Priabonian of the Celebes),
Pirena (*Pseudobellardia*) *delphinus* (Oppenh.) (Kashmir and Borneo; Europe),
Turritella harnaiensis Cox,
Volutocorbis harnaiensis Cox.

Hindubagh, Zhob valley.—At the chromite mines of Hindubagh in the western part of the Zhob district, a small outcrop of Eocene beds is now being exposed by the denudation of recent detritus covering it. The beds lie upon an intrusive mass of serpentine and other ultra-basic rocks and are bent into an asymmetric syncline, the southern vertical limb of which appears to be faulted against the igneous rock. The sedimentaries have been explored by Col. L. M. Davies and are of considerable interest in that they represent a pronounced estuarine facies of the Laki series. They consist of an older limestone which is probably the Meting (Dunghan) Limestone and some younger shales referred to the Ghazij.[71] The mutual relationship of the two stages is of a highly discordant nature not yet understood.

The older stage is an impure, brick-red limestone, full of irregular fragments of serpentine and serpentinised olivine, derived from the rocks below, and containing poorly preserved foraminifera which, so far as they can be made out, resemble the characteristically Lower Laki forms, *Nummulites atacicus* Leym., *Assilina granulosa* d'Arch., and *Alveolina subpyrenaica* Leym; in addition this rock has yielded many small gastropods enclosed in calcareous nodules.

The higher group consists principally of clays full of disseminated gypsum and including a few intercalated bands of limestone; in the

[69] Q.J.G.S., Vol. 81, 420 (1925).
[70] Trans. Roy. Soc. Ed., Vol. 57, 25 (1931).
[71] Trans. Roy. Soc. Ed., Vol. 56, 500 (1930).

northern limb of the syncline these low-dipping shales contain some lignite bands in their lower portion. While the limestone bands are full of foraminifera, the clays abound in mollusca, the following of which have been determined by L. R. Cox.[72]

LAMELLIBRANCHIATA.

Ostraea (Lopha) newtoni (Dalt.),
Ostraea (Liostraea) cf. *rouaulti* Moll. (Europe),
Trapezium cyclopeum (*Brongn.*) (S. Europe),
Lucina (Pseudomiltha) undata Cox,
Diplodonta hindu Cox,
Cyrena pilgrimi Cox,
Meretrix (*Cordiopsis incrassata* (J. Sow.) (Europe, Caucasus, Egypt and Nigeria),
Cardium cotteri Cox,
Corbula (Bicorbula) subexarata d'Arch. & H. (numerous).

GASTROPODA.

Cerithium baluchi Cox,
Ampulella nuttalli Cox,
Potamides pascoei Cox,
Potamides (Pyrazus) indicus Cox,
Thiara vredenburgi Cox.

Among the foraminifera found in the bands of somewhat coarse limestone the genus *Nummulites* is curiously rare and *Alveolina* seems to be totally wanting. The former, however, is represented by a form closely resembling *N. mamillus* Ficht. & Moll., found elsewhere in the Laki limestones, and in the somewhat higher horizon of the basal Kohat Shales; *N. mamillus* itself is characteristic of the Lower Eocene of Europe. The foraminifera collected and described by Col. Davies from these limestone bands comprise the following:

Nummulites cf. *mammillus* Ficht. & Moll.,
Dictyoconoides vredenburgi (Dav.),
Lituonella douvillei (Dav.),
Coskinolina balsilliei Dav.,
Dictyoconus indicus Dav. (resembling *D. aegyptiensis* Chapm.),
Smaller foraminifera belonging to the Miliolidae and Textularidae.

The Ghazij shales would appear to correspond approximately to the upper two of the three Laki stages, *i.e.*, to the Meting Shales and Laki Limestone. In Sind the Lower Kirthar is missing and the Laki Limestone is succeeded unconformably by the Middle Kirthar. On the other hand, it is the Ranikot which is absent in the Marri and Bugti Hills, in the Loralai district, and throughout the Kalat State, where the Dunghan Limestone is the lowest stage of the Tertiary represented.

Southern Baluchistan.—Several outcrops, some of them of appreciable size, were at first mapped and recorded as Ranikot in the Chagai district of Baluchistan and along its southern borders, from Koh-i-Malik Siah, the extreme western point of the district, to the extreme eastern end beyond Nushki. These beds are now known to belong to the Laki series. If everywhere correctly correlated,

[72] Trans. Roy. Soc. Ed., Vol. 57, 25 (1931).

there is likely to be found a more or less continuous arc-shaped outcrop of these beds between these two points, transgressing into Persia, Kharan and Sarawan.

At the Nushki end are friable shales and sandstones, much contorted but with no indications of slaty cleavage, containing well preserved fossils including nummulites, alveolines, operculines, species of *Cerithium* and other fossils of which no collection unfortunately was made. Conglomerates of volcanic pebbles are associated with these sediments. In the same vicinity are calcareous shales of brilliant red and green and associated with similar conglomerates and pebble bands ; the age of these beds, which recur throughout the district, is less certain, but they become interbedded in places with limestones containing shattered fossils which may be of Laki age.

Further west, the Laki hills,[73] south of Malik Gatt (Gatt-i-Barot), consist of gypsiferous shales and tuffaceous sandstones of bright colour overlain by a coralline limestone. These strata are highly disturbed and crushed, and the fossils contained therein distorted ; amongst the latter is *Astrocoenia blanfordi* Dunc., a typical Upper Ranikot coral.

In the west the Eocene series, bent into a syncline, includes the green shales and calcareous sandstones, whose Laki age is surmised rather than proved. The limestones on Koh-i-Robat, on the other hand, contain numerous foraminifera—nummulites, alveolines and operculines—, some very large echinoids belonging to *Conoclypeus*, and abundant specimens of a variety of *Arachniopleurus semireticulatus* Dunc. & Slad., a characteristic coral of the Sind Laki. At Koh-i-Malik Siah occur over 1,000 feet of grey shales with some intercalated limestone bands containing nummulites, including *N. atacicus*, alveolines and in their uppermost layers, *assilina exponens* ; these are overlain by a great mass of limestone several hundred feet in thickness, the base of which has also yielded fossils. Among these beds there is little if any of the interbedded volcanic material so common in the Cretaceous strata below.[74]

The Sulaiman Range.—Along the northeastern margin of Baluchistan, in the Sulaiman Range, both the Dunghan and Ghazij series have been recognised. For that portion of the range lying between Drug on the north and Fort Munro on the south, a distance of about 40 miles, Nuttall gives the following generalised section.[75]

Ghazij Shales :	**Blue-grey fissile shales with thin limestone bands in the upper part containing *Nummulites atacicus* and *Assilina granulosa*.**	**—about 2,000 ft.**
Dunghan Limestones :	**Hard, dark, conglomeratic limestone, interbedded with olive shales containing *Alveolinae*.**	**—about 500 ft.**

Throughout the Sulaiman foothills.—The Dunghan Limestone rests with an unconformity, of which there is no visible sign, on

[73] Not to be confused with the range in Sind.
[74] Mem. 31 196 & 198 (1901).
[75] Rec. 59, 118 (1926).

the Pab Sandstones of the Cretaceous; the actual break between the two formations corresponds to the Ranikot and the *Cardita beaumonti* beds. Near Fort Munro which, incidentally, is some 150 miles E.N.E. of the Bolan Pass, the base of this series is described by Vredenburg as lateritic.[76] It is probably this limestone which, farther south, gives rise to a long, well marked, unbroken ridge known as the "White Range".[77] In the Takht-i-Sulaiman area (Sherani Hills), the Dunghan consists of 250 feet of massive and very hard, grey limestone, capping quartzose sandstones of Cretaceous age which are the equivalent of the Pab sandstones. No recognisable fossils have hitherto been extracted from the limestone, but its weathered surfaces are crowded with sections of what appear to be alveolines.[78] Here it forms a lofty serrated ridge, rising from the east at a dip of about 30° and precipitously scarped on the west; northwards it thins out and for a mile or two is wanting, but reappears in the Zao river section.

In the neighbourhood of the Takht, the Ghazij group is probably included in the lower part of La Touche's "stage 7" which consists of 9,000 or 10,000 feet of shales and sandstones in the greater portion of which there are no fossils except some obscure plant impressions; a few insignificant strings of coal occur. Near the base of this stage, greenish and reddish shales and clays are most conspicuous; higher up these become interstratified with bands of soft, grey sandstone, weathering red, and sometimes coarse, gritty bands with current-bedding. These argillaceous rocks, which show only a slight indication of shaly bedding, occupy nearly all the slopes of the low hills immediately east of the Takht range, a country much dissected into ravines.[79] The Ghazij Shales of this area are followed by what may be the lower Kirthar. In the southern portion of the Sulaiman range Blanford traced the olive shales of the Ghazij group for over 50 miles along the flank of the main range and records the scarcity and thinness of the limestone bands and the presence near the top of the stage of beds of white gypsum.

Seepages of oil occur in the neighbourhood of Moghal Kot, at the foot of the southeastern slope of the Takht-i-Sulaiman range on the western Punjab frontier; these indications occur in a sandstone belonging to the "Middle Nummulitic" beds of La Touche, corresponding probably to the Ghazij group.[80]

Griesbach has expressed the opinion that the Ghazij clays will be found in the lower Zhob and Gumal valleys.[81]

Waziristan.—In Waziristan much of the true Eocene appears to be absent. In the Takki Zam valley southeast of Kaniguram faulted between the Neocomian shales on the west and the Siwalik outcrop

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[76] Rec. 36, 184-185 (1907).
[77] Mem. 20, 226 (1883).
[78] T. H. D. La Touche, Rec. 26, 82 (1893).
[79] C. L. Griesbach, Rec. 17, 188 (1884).
[80] Rec. 25, 172 (1892).
[81] Rec. 17, 188 (1884).

of which stands Jandola, on the east, is a thin belt of olive green and chocolate shales associated with a dark brown sandstone and grit weathering to a shiny black surface; in the green shales are thin intercalations of a black flaggy limestone and a thick band of a red nodular variety of the same rock.[82] Although no fossils have been found in these beds, they appear to be equivalent to similar beds seen further north in the Tochi valley and believed to represent the Ghazij Shales. In the Takki Zam valley they are succeeded by a thin band of white limestone, forming the Palesina ridge and the Sagarzhai, and possibly a member of the Kirthar series.

Overlying the Cretaceous sandstone of Shahur Tangi in southern Waziristan are a few red shales containing grits with abundant foraminifera, such as *Rotalia* and *Textularia*, and other organic structures which may belong to the Radiolaria and Diatomaceae.[83] These beds, doubtfully assigned to the Laki, are overlain by Kirthar beds including the limestones in the Sagarzhai ridge and at Jandola. Southwards these supposed Laki shales and grits continue to the Shirani hills, west of Dera Ismail Khan where they are correlated with the Ghazij Shales; northwards they have been traced at least as far as Kotkai.[84]

According to Col. Davies, the Laki beds of Kohat thin out westwards and at the northwestern extremity of the district, along the Waziristan frontier, a few feet of Kirthar beds are seen superposed discordantly upon the Ranikot.[85]

In the Tochi (Tachi) valley, 30 or 40 miles farther north, underlying Siwalik strata is a bed of hard, white, nodular limestone which, where it crosses the river at Shinkai, is 170 feet thick. The irregularities in the upper surface of the limestone are filled up by the Siwalik sandstone, the lowest two feet of which also contains many limestone pebbles. Westwards this thin limestone, which may be assigned tentatively to the Kirthar, rests conformably on several thousand feet of a series consisting essentially of shales and described as very like the Ghazij Shales of the Quetta area.[86] These soft beds show considerable contortion but are folded in a flat anticline, the core of which is occupied by the Idar Khel plain between Idak and Miram Shah. They consist in the main of soft, greenish brown to red shales, with frequent partings of soft, buff to brown sandstone weathering characteristically to a shiny black on the surface. At certain parts of the section the shales are interbedded with shaly limestone and limestone breccia, the latter containing many fossils but not observed nummulites; near Idar Khel the sandstone layers nearly white in colour, increase in size and alternate rapidly with layers of limestone. Some of the calcareous sandstones show traces

[82] Murray Stuart, Rec. 54, 92 (1922).

[83] Gen. Rep. Rec. 72, 22 (1937).

[84] Gen. Rep. Rec. 73, 83 (1938).

[85] Soc. geol. de France, Compte Rend., 22-23 (1938).

[86] F. H. Smith, Rec. 28, 108 (1895).

of foraminifera. Some of the limestone bands are full of corals and broken bivalve shells; amongst the latter Dr. L. R. Cox has recognised *Gryphaea (Pycnodonta) brongniarti (Bronn)*. *Foraminifera*, on the other hand are rare and badly preserved, except in some yellow limestones interbedded with blue slaty shales around Dotoi. These limestones, which are full of well preserved nummulites of all sizes, are said to be different from the white Kirthar limestone and indeed from any other of the limestones of the area; whether it is the equivalent of the Dunghan or not remains for further investigation to decide, but in the opinion of Pinfold, the Dunghan limestone is absent in Waziristan.[87]

Westwards the Eocene limestones and shales rest abruptly on a series of beds which have been intruded and altered by basic igneous rocks which Mr. Smith suggests began to be injected prior to the Tertiary period. In the midst of these intruded beds is another outcrop of the supposed Kirthar limestone.

Cutch.—Above the Sub-nummulitic beds of Cutch there are in places from 50 to 100 feet of fine laminated shales, bituminous and often pyritous, with fragments of wood and leaf impressions.[88] The gypseous shales which follow (see page 1486) form a local and unimportant subdivision, from 50 to 150 feet in thickness, occurring in western Cutch, round the Gaira Hills and in a few other places. They consist of shales, with calcareous nodular bands and much gypsum, and with some beds of laterite. Some of the marly beds abound in nummulites, other foraminifera, oysters and other fossils. These beds belong to some part of the Ranikot-Laki-Kirthar sequence. Some of the nummulites have their chambers filled with bitumen.[89]

Kathiawar and Baroda.—Occurrences of natural gas on both sides of the Gulf of Cambay witness to the probable presence of Eocene beds below a large proportion of the gulf itself and the alluvium at its head.[90] The gas, which has been met with in a well at Jagatia in Kathiawar, and in others at Gogah (Gogha; Gogo) in Bhawanagar, is under no great pressure and consists almost entirely of methane; from one of the Gogah borings the gas shows traces of helium.[91] None of the wells yielded any of the higher homologues of methane. One of the Gogah borings also yielded at a depth of 620 feet, a soft white, nummulitic limestone, for which a Kirthar age has been suggested by Capt. Palmer;[92] in the same boring, apparently, Deccan Trap was met with at a depth of 185½ feet, so that the Eocene limestone lies below the Trap. The Tertiary beds above the Trap belong to the Gaj (Miocene).

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[87] Rec. 74, 195 (1939).

[88] In the Eocene of Cutch Lydekker identified *Myliobatis curvipalatus* Lyd. (Pal. Ind., Ser. 10, Vol. 3, No. 8, p. 4, (1886).

[89] Gen. Rep. Rec. 33, 77 (1906).

[90] Gen. Rep. Rec. 68, 42 (1934).

[91] P. K. Ghosh, Rec. 69, 433 (1935).

[92] Gen. Rep. Rec. 54, 27 (1922).

(iii) Middle and Upper Eocene.

Distribution and subdivision.—The Middle and Upper Eocene are represented in western India by the Kirthar (Khirthar) series, named after the most important range of western Sind, where its highest members are prominently developed. This range, which forms the western frontier of Sind, probably continues southwards beneath the Arabian Sea as the Murray Ridge.[93] The term, Kirthar, originally included the Laki beds which were subsequently separated as an individual group. The Kirthar series has been recognised in Cutch, Baluchistan, western Sind, the North-West Frontier and the Punjab, and comprises massive white, nummulitic limestones and olive to grey shales, lithologically similar to the rocks of the Laki series, to which in a few places they succeed conformably. It corresponds to the Mokattam of Egypt. The series has a different nummulitic fauna from that of the Laki and has been divided into three stages, Lower, Middle and Upper. Its distribution in Sind and Baluchistan is shown on the map compiled by Mr. E. Vredenburg,[94] who is responsible for the following subdivision:[95]

Upper. Massive white limestones with *Nummulites aturicus* and *N. complanatus*.

Middle. Massive limestones with *Nummulites laevigatus* and *Assilina spira*.

Lower. { Kirthar Shales; thin-bedded shales, limestones and sandstones. Ghazaband limestone; black limestone with *Assilina exponens*, and species of nummulites of somewhat doubtful determination.

Sind and Baluchistan.—The Spintangi formation.—In Baluchistan the uppermost Cretaceous, wherever present, is in the majority of cases succeeded immediately by beds of typically Middle Eocene age.

In spite of the superb sections of the Tertiary displayed in western Sind, the Kirthar is not so completely developed here as it is in various parts of Baluchistan, the lowest stage being unrepresented on the Sind side of the Kirthar range. In fact, throughout Sind the Ghazij beds and Lower Kirthar of Baluchistan are absent, and the Laki Limestone is overlain unconformably by the Middle Kirthar.[96] In the Marri country, the Loralai district and the eastern part of Quetta, the Ghazij Shales are overlain conformably by what R. D. Oldham called the Spintangi group, named after the type locality in northeastern Baluchistan (*spintangi*, "the white gorge"). This group he afterwards identified with some part or all of the Kirthar, an identification of which there is good reason to believe is correct. Vredenburg was inclined to correlate the group with the Upper Kirthar only, but it certainly includes the Middle stage, and probably also the Lower, of the Kirthar. Nuttall, like Oldham finds no sharp line separating the Spintangi beds from the Ghazij Shales, and the latter authority found the Shales passing up into the basal Spintangis

[93] J. D. H. Wisemann & R. B. S. Sewell, Geol. Mag. 74, 220 (1937).
[94] Pal. Ind., New Ser., Vol. 3, pt. 1, fig. 9 (1909) also Rec. 38, Pl. 12 (1909).
[95] Rec. 38, 198-199 (1909).
[96] W. L. F. Nuttall, Q.J.G.S., Vol. 81, 419 (1925).

near Khattan. The survey of this region requires revision and systematization, such as that commenced by Nuttall.

Oldham's Spintangi group consists of a nodular limestone at the base followed by shales with beds of marl, gypsum and limestone, the limestone bands, many of which are nodular, predominating towards the top. The close association of clear, fossiliferous limestones of presumably deep water origin with beds of gypsum is interesting. The latter are in places of considerable thickness ; on the scarps near Mamand one of the gypsum beds is 50 feet thick and four others aggregate 33 feet in a total of 400 feet of strata. One section is recorded in which the Spintangi beds appear to be 1,000 feet or more in thickness ; towards Shahrig the group is said to be reduced to 60-100 feet of limestones. The Spintangi beds occupy higher ground than the softer Ghazij shales, and are overstepped by Siwalik strata.[97] Probably from the basal Spintangi comes *Dictyoconoides kohaticus* and its variety, *spintangiensis*.[98] From the Spintangi of the Zhob district are recorded: *Gisortia* (*Vicetia*) *depressa* Sow., and G. gigantea Münst. (included by Vredenburg in *G. gisortiensis* Valenc.)[99]

Certain beds of the Spintangi limestone near Sukkur and in Baluchistan are said to resemble the Nummulite Shale of the Potwar area,[100] containing the same peculiar association of a globose oyster with nummulites ; the Spintangi beds differ in possessing usually a calcareous matrix, though in places they are no more than a loosely compact nummulitic shale. At Sukkur, the nummulites, of which *N. laevigatus* (Brug.) *and N.* aff. *scaber* Lam. are very *abundant,*[101] have in many cases been attacked by a parasitic organism.[102] They are all Middle Kirthar forms and include, besides the two already mentioned, *Nummulites carteri* d'Arch. & H., *N. gizehensis* (Forks.), *Assilina cancellata* Nutt. (common), *A. subcancellata* Nutt. (megalospheric form of the preceding ; common), *A. spira* de Roissy (abundant). *A. papillata* Nutt., *A. subpapillata* (megalospheric form of the preceding, with which it always occurs).[103] At Spintangi itself, however, the uppermost levels of the Eocene section, according to Col. Davies,[104] have a distinctive fauna belonging to the Upper Kirthar and including *Dictyoconoides kohaticus,* var. *spintangiensis* and *Nummulites beaumonti*. The latter species in Europe ranges from Auversian to Bartonian, and its presence at Spintangi is proof, in the opinion of Col. Davies, that the section there includes higher levels than any found at Harnai, 16 miles to the northwest. The *forma typica, Dictyoconoides kohaticus* abounds both at Harnai and at lower levels in the Spintangi section.[104] Some four miles east of Rohri portions of the nummulitic limestone are recorded by La Touche as containing

[97] R. D. Oldham, Rec. 23, 96-98 (1890) ; Rec. 25 23 (1892).
[98] L. M. Davies, Rec. 59, 245 (1926).
[99] Rec. 51, 128 (1920).
[100] E. S. Pinfold, Rec. 49, 145 (1918).
[101] W. L. F. Nuttall, Rec. 59, 135-136 (1926).
[102] Gen. Rep. Rec. 33, 77 (1890).
[103] W. L. F. Nuttall, Rec. 59, 139-145 (1926).
[104] Col. L. M. Davies, Private Communication.

nests and strings of rock-salt.[105] A boring for oil in the vicinity of Sukkur encountered only gas.[106]

(a) LOWER KIRTHAR.

General character and distribution.—With few exceptions the lithology of the Lower, like that of the Middle Kirthar, is very cons tant in western India, and is characterised by alterations of creamy white nummulitic limestone and fine grey shales, both stages are devoid of coarse sediments and, as noted by Nuttall, must have accu mulated in a tranquil sea of moderate depth.[107]

In the eastern parts of Kalat State, the Lower Kirthar includes a black, brecciated or conglomeratic limestone at the base, but the bulk of the stage is described by Vredenburg as a succession, aggregating several thousand feet, of unfossiliferous shales, with occasional intercalated calcareous or arenaceous bands in which foraminifera are to be found.[108] The basal black Ghazaband Limestone, according to Vredenburg, is to be found in the Mulki and Palki range, the first series of ranges west of the plains of Kharzan, of Warum and of Karu, and in many other localities where the Kirthar Shales are exposed. The latter are recorded in the plains of Gazk and Zahri; in the valley of the Gidar Dhor; south of Gidar and Chad; in the plains of Bhagwana, Khozdar, Zidi, Kharzan, Warum and Karu; in the synclinal valleys of the upper Mula, of the Hanjira and several of their tributaries, in the Gaj and Hab valleys, and elsewhere.[109] In the valley of the Hab, the Lower Kirthar has a flysch-like development.

The Lower Kirthar rocks of the Dera Ghazi Khan district in the Punjab, and of the Loralai district, the Bugti Hills and Bolan Pass in Baluchistan, are described by this observer as consisting of from 1,500 to 2,500 feet of massive, white, scantily fossiliferous limestones, with local intercalations of shale and occasionally of sandy or gypseous bed.[110] They rest conformably on the Ghazij Shales and have yielded the following foraminifera: *Nummulites atacicus* Leym. (and *N. subatacicus* Douv.) (abundant), *Orbitolites complanata* Lam., *Assilina exponens* (Sow.) (including *A. mamillata* (d'Arch.); common);

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[105] T. H. D. La Touche, in Geological notes, Rec. 28, 88 (1895).
[106] T. H. D. La Touche, Rec. 28, 55-58 (1895).
[107] Geol. Mag., 63, 496 (1926).
[108] Vredenburg records from these beds the following foraminifera but it seems likely that some of his identifications are erroneous or that his Lower Kirthar includes some of the Middle Kirthar of Dr. Nuttall and perhaps even Upper Laki (Ghazij) horizons:

(i) Ghazaband Limestone. *Assilina exponens*; *Nummulites irregularis*. (a Laki species, frequent in the Ghazij shales); *N. laevigatus* (see above); and *N. perforatus* (see above), type and var. *obesus*.

(ii) Kirthar Shales. *Assilina exponens*; *Nummulites laevigatus* (according to Nutall, rare in the lower part but abundant in the upper part of the Middle Kirthar); and *N. perforatus* (=*N. obtusus*, which is rare in the Lower but plentiful in the Middle Kirthar).

[109] Rec. 38, 199 (1909).
[110] W. L. F. Nuttall, Rec. 59, 120 (1926).

and *Nummulites obtusus* Sow. (including its megalospheric form, *N. perforatus* (de Montf.) ; rare). *N. obtusus* marks the first appearance of pilate nummulites.

From what is believed to be the Lower Kirthar in the Harnai district the equivalent of the Kohat Shales further north, come the two lamellibranchs, *Lucina* (*Loripinus*) *kohatica* Cox, and *Cardium* (*Discors*) *burnburyi* d'Arch. & H.[111]

Chagai.—Near Saindak, in the extreme west of the Chagai district of Baluchistan, is a series of shales and limestones, the former of which are frequently brightly coloured. The lowest fossiliferous horizon contains in abundance the most characteristic Kirthar fossils, the succession rising as far up as the Nari series. At Sheikh Husain, on the other side of the eastern boundary of this district and therefore in the State of Kalat, another small patch of Kirthar shales and sandstones has been mapped by Vredenburg, containing among other Kirthar fossils, *Assilina granulosa* and *Gisortia* (*Vicetia*) *depressa* Sow.; possibly some of the slates in the neighbourhood may be metamorphosed Eocene strata belonging to the Middle or even Upper division.[112]

Makran.—Along the Makran coast, between Gwadar and Jaskh, Tipper has collected: *Nummulites* aff. *lyelli* d'Arch. & H., *N.* aff. *vicaryi* d'Arch. & H., *Assilina exponens* (Sow.) and a form doubtfully identified as *Orbitoides mantelli* d'Orb. The same observer records Eocene rocks crowded with Kirthar nummulites in stream-beds around the Bampur plain in eastern Persia.[113]

The Sulaiman Range.—In the Sulaiman range Dr. Nuttall records the following generalized section of the Lower Kirthar,[114] overlying the Ghazij Shales and underlying the basal Middle Kirthar:

	ft.
Blue-grey shales weathering olive green, with much secondary gypsum in the form of clear selenite crystals ; near the top a brown sandy limestone crowded with *Ostraea*	900
Limestone with grey to black chert bands	40
Persistent bed of massive white amorphous gypsum . . .	15
Blue-grey shales	400
Massive white limestone with *Nummulites atacicus* . . .	1,300
	2,655

The upper portion of the above section is recognisable further north in the latitude of the Takht-i-Sulaiman, and evidently corresponds to "stage 8" of La Touche.[115] In the latter, which succeeds "stage 7" without any break, there appear, among the predominant shales, bands of limestone containing nummulites, bivalves, corals

[111] L. R. Cox, Trans. Roy. Soc. Ed., Vol. 57, 74 and 83 (1934).

[112] Mem. 31, 198 and map (1901).

[113] Rec. 53, 64-65 (1921) ; see also W. T. Blanford, Rec. 5, 41-45 (1872).

[114] Probably belonging to this horizon are the specimens of *Dictyoconoides Kohaticus*, var. *blanfordi* Dav, collected by Balnford just west of Mangrotah in the Dera Ghazi Khan district, *i.e.*, east of the Sulaiman range (L. M. Davies, Rec. ⁵9, 246 (1928).

[115] Rec. 26, 82 (1893).

and other organic remains in abundance. Closely associated with these marine bands are numerous beds of saccharoid gypsum; gypsum sometimes occurs in cavities in the limestone. In the latter case the limestone weathers more readily than the gypsum, the result being a rock which appears to be studded with snow-balls. The shales accompanying the gypsum are vividly coloured. La Touche correlates his "stage 7", which is nearly 10,000 feet thick, with the Ghazij Shales and, from his description, there is no part of it which tallies with the massive white limestone, 1,300 feet thick, with *Nummulites atacicus,* which forms more than the lower half of the Lower Kirthar further south, and which has just been described. Possibly we have here a repetition of the overlap seen in southern Baluchistan and Sind, but the suggestion requires confirmation.

(*b*) MIDDLE AND UPPER KIRTHAR.

Distribution.—The Middle Kirthar is the only stage extensively developed on the Sind side of the Kirthar range, its massive white limestones occupying ridges in the northwest of the province, the principal being the Bhit, Badhra, Dumbar, Bedur and Kambu. Along the western slopes of the Surjana range and at the northern end of the Kara range, the Kirthar and Laki limestones are in contact with each other.

Sind and Baluchistan.—From the Kirthar of Sind, and therefore most probably from the Middle division of the series, the following mollusca have been determined by Dr. L. R. Cox.[116]

LAMELLIBRANCHIATA.

Ostraea multicostata Desh. (Europe, N. Africa, Turkistan and Jamaica)
Gryphaea (Pycnodonta) brongniarti (Bronn),
Cardita funiculosa d'Arch. &. H..
Blagraveia corrugata Cox,
Cardium halaense d'Arch. & H.,
Cardium (Discors) bunburyi d'Arch. & H.

GASTROPODA.

Velates perversus (Gmel.),
Ampullina (Pachycrommium) flemingi (d'Arch. & H.),
Terebellum carcassense Leym.,
Conus sp.,
Gosavia humberti (d'Arch. & H.).

In Baluchistan the Middle Kirthar includes horizons richest in nummulites, and has been divided by Vredenburg into two zones, a lower which is partly calcareous but has frequent shaly intercala-

[116] Trans. Roy. Soc. Ed., Vol. 57, 25-86 (1934); Locality "Alore Hills", near Rohri.

tions, and an upper which is mainly calcareous.[117] According to this authority, the Middle Kirthar is present in the synclinal valley of Drang in northeast Sarawan, in Melabi hill, on the Sarun plateau, in the Harboi range and all the hills forming part of the great Eocene plateau of southern Sarawan and northern Jhalawan, in the Mishkin and other limestone ranges west of the Gidar Dhor in the Lower Mula synclinal valley, in the Kirthar range, and in the Bedur, Chapar and other ranges along the lower Hab. Along parts of the Laki range, the Laki Limestone is directly and unconformably overlain by the Middle Kirthar, the Lower Kirthar stages being absent.

The Middle Kirthar of Baluchistan is divided by Nuttall into two sub-stages showing marked faunal differences and separated from each other by a non-sequence. Throughout the greater part of this region either the lower or the upper part of the Middle Kirthar is overlain unconformably by Oligocene or Miocene beds, the chief exceptions being the Mula Pass and the Kirthar range where the Upper Kirthar is said to be present. The lower sub-stage is characterised by a large *Alveolina*, a large *Dictyoconoides* and a large *Discocyclina*, the last being a common form; with the radiate nummulites, *N. beaumonti* (or a variety thereof) and *N. stamineus*: in the upper substage radiate nummulites are rare, while a large assilina is typical. The lower part of the Middle Kirthar is described as consisting of not more than 1,300 feet of massive, white limestones and shales containing abundant foraminifera. In most places it has a higher proportion of shale than the Lower Kirthar; these two groups, however, are otherwise indistinguishable lithologically, the one passing conformably up into the other. Form this lower sub-stage Nuttall records the following:[118]

FORAMINIFERA.

Nummulites atacicus Leym. (with *N. subatacicus* Douv.) (abundant),
Nummulites obtusus Sow., (abundant),
Nummulites acutus Sow. (including *N. djokdjokartae* Mart.; frequent),
Nummulites beaumonti d'Arch. & H., (frequent)[119],
Nummulites maculatus Nutt. (rare),
Nummulites stamineus Nutt. (frequent),
Nummulites laevigatus (Brug.) (including *N. lamarcki* d'Arch; rare),
Orbitolites complanata Lam.,
Assilina exponens (Sow.) (including *A. mamillata* d'Arch.),
Dictyoconoides cooki (Carter) (abundant),

[117] According to Vredenburg these zones are characterised by the following foraminifera, but again their identification and stratigraphical position leave some doubt:

(i) Lower. *Assilina exponens, A. sufflata* (? *A. Papillata* Nutt., *N. laevigatus, N. perforatus* (see above), *N. discorbina* (see above), and *N. gizehensis* (Forks) (? should be in upper and not lower zone).

(ii) Upper. *Assilina exponens, A. spira, Nummulites carteri, N. beaumonti* (? should be in the lower and not the upper zone), *N. marchisoni* (Species not found by Nuttall in Western India) *N. perforatus* (= *N. Obtusus*) and *N. discorbina* (?=*N. stamineus*).

[118] Geol. Mag., Vol. 63, 498-499 (1926); Rec. 59, 120-121 (1926).

[119] According to col. L. M Davies, this is a variety of *N. beaumonti*.

Actinocyclina alticostata Nutt. (rare),
Discocyclina dispansa (Sow.) (abundant),
Discocyclina javana (Verb.), var. *indica* Nutt. (very abundant),
Discocyclina undulata Nutt. (rare),
Discocyclina sowerbyi Nutt. (common),
Alveolina elliptica (Sow.) (common).

The upper part of the Middle Kirthar has been recognised by Dr. Nuttall in the range southeast of Damach, a village in the Khano Bula Than *taluk* of the Karachi district, in the Laki range west of Laki village, and in the hills to the south of Rohri in Sind. The following foraminifera have been collected from 300-400 feet of limestones and shales, but the total thickness of the beds is not known since the lower and upper boundaries have not yet been observed in the same section:

Nummulites obtusus Sow.[120] (including *N. perforatus* de Montf.), (common).
Nummulites laevigatus (Brug.) (Including *N. lamarcki* d'Arch.; abundant),
Nummulites aff. *scaber* Lam. (abundant),
Nummulites carteri d'Arch. & H. (1) (rare),
Nummulites gizehensis (Forks.) (rare),
Orbitolites complanata Lam. (rare),
Discocyclina sowerbyi Nutt. (rare),
Alveolina elliptica (Sow.) (rare),
Assilina cancellata Nutt. (including *A. subcancellata* Nutt.),
Assilina papillata Nutt. (including *A. subpapillata* Nutt.) (common),
Assilina spira de Roissy (frequent).

The following is a list, compiled by Vredenburg, of the echinoids found in the Kirthar series;[121] it is inserted here since the fossils are described as derived "almost entirely from the calcareous shales of the Middle Kirthar",[122] principally from Vredenburg's lower zone and the immediately overlying portion of the upper:

Coptosoma undatum Dunc. & Sladen.[123]
Conoclypeus pinguis D. & S.,
Conoclypeus rostratus D. & S.,
Conoclypeus galerus D. & S.,
Sismondia polymorpha D. & S..
Amblypygus patellaeformis D. & S.,
Amblypygus tumidus D. & S,
Amblypygus latus D. & S.,
Echinolampas sindensis d'Arch.,
Echinolampas sindensis var. *hemisphaerica* D. & S. (found in Bahrain Island),[124]
Echinolampas angustifolia D. & S.,
Echinolampas juvenilis D. & S.,
Echinolampas aequivoca D. & S.,
Echinanthus intermedius D. & S.,

[120] *Numulites carteri, N. obtusa, N. aturica* and *N. intermedia* from India, in a few cases show a curious reversal in the direction of spiral growth (Rec. 33, 77 (1906).

[121] Blanford's lists of the mollusca are not given since the Laki and true Kirthar forms are not distinguished (Mem. 17, 201 (1879)

[122] Rec. 34, 192 (1906).

[123] Sec. Journ. Linn. Soc. Zool., Vol. 23, 88 (1891).

[124] Pal. Ind. New Ser., Vol. 22, No. 1, 12 (1933).

Ilarionia sindensis D. & S.,
Cassidulus subinvaginatus D. & S.,
Micraster tumidus D. & S.,
Linthia orientalis D. & S.,
Schizaster simulans D. & S.,
Brissopatagusindensis D. & S.
Peripneustes sp.,

The following mollusca come from the Kirthar of the Marri and Bugti hills, but from which stage is not in all cases known:[125]

LAMELLIBRANCHIATA.

Vulsella legumen d'Arch. & H.,
Meretrix cf. *sulcataria* (Desh.) (Europe & Egypt),
Cardium cotteri Cox,
Spondylus radula Lam (Europe and Egypt),
Cardita sindensis Cox (Middle Kirthar),
Cardita subcomplanata d'Arch. & H. (Middle Kirthar)

GASTROPODA.

Velates perversus (Gmel.),
Cepatia cepacea (Lam.),
Terebellum carcassense Leym.,
Gosavia humberti (d'Arch. & H.),
Involuta daviesi Cox.,
Gisortia gigantea Münst. (included by Vredenburg in *G. gisortiensis* Valenc.[126] also found in Sind and Assam).

According to Vredenburg, the Upper Kirthar is present along the lower Mula valley and the Kirthar range, as well as being represented in the Spintangi beds of northern Baluchistan. and consist of a massive white limestone containing *Nummulites aturicus* and *N. complanatus*. These are Middle Kirthar forms, however, and the limestone probably belongs to this stage. Colonel Davies suggests that the Upper Kirthar is of limited and local development, and characterised by *Dictyoconoides kohaticus*, var. *spintangiensis* Dav., *Alveolina elliptica* (Sow.) a new and well marked species of *Assilina-A. rota* Dav., *Nummulites obtusus* (Sow.), and true specimens of *Nummulites beaumonti*, the *forma typica* of which does not occur in the two older stages, but is there represented by a variety. As already stated, the true Upper Kirthar is present in the Spintangi section.[127]

It is probably to the Middle Kirthar, therefore, that we must refer the limestone which forms the main ridge of the Kirthar, a range having a general N.—S. direction but curved convexly towards the west, with an average height of 4,000-5,000 feet and a maximum peak, Kutta-jo-kabar ("the dog's tomb") over 6.000 feet. This frontier range is cut through by the gorge of the Gaj river which rises to the west of it; in places it coincides with the axis of an anticline which elsewhere lies to the west of the frontier.[128] East of the

[125] L. R. Cox, Trans. Roy. Soc. Ed., Vol. 57, 25 (1934).
[126] Rec. 51, 128 (1920).
[127] L. M. Davies, Q. J. G. S., 96, 199-230 (1940).
[128] Mem. 17, 25-26 (1879).

main ridge are irregular subsidiary ranges of newer Tertiary strata. The most conspicuous rock in the range, and one which forms its crest throughout, is a massive, white or light grey nummulitic limestone composed chiefly of foraminifera, especially nummulites, whole or fragmentary; corals, echinoids and molluscs also abound. Vredenburg speaks of this stage as consisting of a vast thickness of enormously massive limestones, but included therein the bulk of the Spintangi beds; from a few hundred feet in lower Sind, this limestone is described by Blanford as increasing in thickness northwards to 1,000-1,200 feet at the Gaj river, and to 2,000 or even 3,000 feet farther north, but whether Lower Kirthar horizons are included in these figures is not certain. The upper limits of the Kirthar probably need revision. Vredenburg divided the upper part of the sequence into four zones which should be accepted with reservation; they are as follows.[129]

4. Limestone of the same thickness as No. 2, with *Assilina spira* (often of very large size) and *Nummulites "perforatus"* (*obtusus*)
3. Limestone, more than one-third of the whole in thickness, its only nummulite being *Nummulites perforatus* (*i.e.*, *N. obtusus* Sow.).
2 Limestone, developed occasionally, only when the stage is at its maximum thickness, often crowded with only one species which is *Nummulites complanata*.
1. A very compact limestone with scarcely determinable foraminifera including: ? *Nummulities brongniarti*, ? *N. biarritzensis* (? *N. atacicus* or *N. stamineus*), and a very small form, ? *N. variolarius*; found only in the Mula Pass

In most of the hill ranges of Sind, the Upper Kirthar is not seen, the Middle stage being succeeded by the Oligocene Nari beds.

The Sulaiman Range.—The lower part of the Middle Kirthar is well exposed on the flanks of the foothills of the Sulaiman range, between Fort Munro and Drug, where it is underlain by the Lower Kirthar and overlain uncomformably by Gaj beds (Miocene). The lower Middle Kirthar of this region is described by Nuttall,[130] as consisting of a basal band, from 20 to 30 feet in thickness, of pure white limestone, followed by 1,200 feet of brown to blue shales containing much secondary gypsum and, near their base, several calcareous bands almost entirely made up of *Discocyclina undulata*. *D. sowerbyi* and *D. javana*, var. *indica*, and yielding in places *Nummulites atacicus*. Both the basal white limestone and the calcareous bands in the shales above form persistent beds which can be traced for miles; the former, which occupies a prominent strike ridge for over 30 miles, is very fossiliferous, the lower part containing abundant *Discocyclina dispansa* and, in addition, *D. sowerbyi*, *Nummulites beaumonti*, *N. acutus* and *Dictyoconoides cooki*.

From the Middle Kirthar of this region (Dera Ghazi Khan district) comes the lamellibranch *Corbula* (*Bicorbula*) *subexarata* d'Arch.

[129] Rec. 34, 88-89 (1906).
[130] Rec. 59, 118 (1926).

& H.[131] From the same horizon in the neighbouring Loralai district of Baluchistan comes *Blagraveia corrugata* Cox.

Rocks of presumably Kirthar age northwest and west of Sambaza have yielded fossils provisionally determined as: *Terebellum* cf. *distortum, Turritella imbricataria, Stylophora* sp., *Turbo* sp., *Vicarya* sp., *Fistularia elongata, Trochosmilia* sp., *Astrocoenia* cf. *numisma, Cidaris* spine, *Nummulites obtusus, N. exponens.* From the faulted area at Kanikhwa China come *Assilina exponens, A. mammillata* and *Discocyclina dispansa.*[132]

Cutch and Kathiawar.—The Kirthar is probably included in Wynne's "Nummulitic group" in Cutch but since the latter is reported to contain abundant alveolines, as well as other fossils, it may well embrace some part of the Laki as well. The beds are described as pale yellow and white impure limestones in bands of no great thickness, interstratified with marls and sandy beds. The upper portion consists chiefly of marls. While limestones are more abundant below. Nummulites, alveolines and echinoderms of several kinds abound and corals and mollusca are locally common. The "Nummulitics" of Cutch are almost confined to the western part of the State, and occupy a band extending from Lakhpat round the western termination of the Deccan Trap range in the Gaira hills.

The lower part of the Middle Kirthar has been definitely recognised by Nuttall in Cutch, in the form of 500 feet of well-bedded white limestones containing *Nummulites acutus,*[133] *N. maculatus, N. stamineus, N. obtusus, Assilina exponens, Alveolina elliptica, Discocyclina dispansa, D. sowerbyi, D. javana,* var. *indica. Actinocyclina alticostata and Dictyoconoides cooki.*[134] These beds are overlain by about 10 feet of Nari limestone; at their base are 75 feet of shales which rest unconformably on a laterite at the top of the Deccan Trap.

From the Kirthar of Cutch come the following mollusca identified by L. R. Cox:[135]

LAMELLIBRANCHIATA.

Ostraea .multicostata Desh.,
Gryphaea (Pycnodonta) brongniarti (Bronn) (equivalent Sowerby's *Ostraea callifera* and *Gryphaea globosa*).
? *Gryphaea (Liostraea) flemingi* d'Arch. & H.,
Cardium cotteri Cox. ...

GASTROPODA. . . . ..

Velates perversus (Gmel.),
Vulsella legumen d'Arch. & H.[136]

A copious echinoid fauna, including 44 species, from the Tertiary beds of Cutch, had been described by Duncan and Sladen.[137]

[131] L. R. Cox, Trans. Roy. Soc. Ed., Vol. 57, 84 (1934).
[132] Rec., 63, 82 (1930).
[133] "*Nummulites vredenburgi* Prev." or "*N. douvillei* Vred."
[134] Rec. 59, 119 (1926).
[135] Trans. Roy. Soc. Ed., Vol. 57, 25 (1934).
[136] To these may be added *Gisortia (vicetia) depressa* J. de. C. Sow.
[137] Pal. Ind., Ser. 14, Vol. I, pt. 4 (1886).

There is, unfortunately, much confusion regarding the stratigraphical position of many of these forms which, for that reason, are not enumerated here.

In Kathiawar Eocene beds have been recorded from Beyt island off the northwest extremity of the peninsula by Dr. Carter.[138]

Waziristan.—In the Takki Zam valley of Waziristan, beds believed to represent the Ghazij Shales are overlain by a series consisting of a lower and an upper stage, both of shale, and a middle one of limestones. One of these limestones forms the Palesina ridge. In the Sagarzhai ridge and at Jandola there are two or more prominent limestones. From the lower shales and the limestone stage the following provisional identifications point to a middle Kirthar horizon: *Assilina papillata* Nutt., *A. subpapilluta* Nutt., *A. mamillata* (d'Arch.), *A. exponens* J. de C. Sow., *A. spira* de Roisay, *Alveolina javana* Verb., *Dictyoconoides kohaticus* Dav., *Discocyclina dispansa* (Sow.), *Nummulites* aff. *scaber* Lam., *N. laevigatus* (Brug.) and *N. obtusus* Sow.

An outlier of the same Kirthar limestone at Kund, three miles southwest of Kotkai, covers a small thickness of olive shales of estuarine character referred to the Laki by Coulson and contains an abundant gastropod fauna; from this outlier come the following:

FORAMINIFERA.

Nummulites obtusus Sow.,
Assilina spira de Roissy,
Dictyoconoides kohaticus Dav..

LAMELLIBRANCHIATA.

Ostraea sp.,
Cardium picteti d'Arch. & H.,
Pecten sp.,
Fistulana elongata Desh.

GASTROPODA.

Velates perversus (Gmel.),
Cepatia cf. *cepacea* Lam..
Involuta daviesi Cox.,
Gisortia (Vicetia) depressa J. de C. Sow..
Natica cf. *angulifera* d'Orb.,
Cerithium sp.,
Rostellaria sp.,
Voluta sp.,
Conus sp.

The highest Kirthar shales of this locality, developed south of Gumal, northeast of Nili Kach, have yielded the following[139]: *Nummulites acutus* Sow., *Caryophyllia* sp., *Fistulana elongata* Desh., *Cardium (Discors)* sp., *Ceratotrochus* sp., *Meretrix subcyrenoides* (Desh.), *Mesalia* cf. *vermetina* Cossm., and *Turritella (Haustator) imbricataria* Lam. From the Kirthar north of Shahur Tangi come

[138] Geol. Papers of Western India, Bombay (1857), p. 743.
[139] Gen. Rep. Rec. 72, 23 (1937).

Amblypygus subrotundus (Dunc. & Sl.) and species of *Assilina* and *Alveolina*.[140] The ostracod, *Bairdia subdeltoidea* (Münst.) has been found in the Kirthar of Spinkai Ghash.[141]

The most important member of the Palaeocene-Eocene succession in Waziristan is the Ranikot. The Lower Laki (Dunghan limestone) appears to be completely absent, and the Upper present only in the south in a much reduced thickness. In some parts of Waziristan, according to Mr. Pinfold, the Lower Tertiary sequence is entirely unrepresented, Upper Siwalik rocks (Pliocene or Pleistocene) resting directly upon the Cretaceous Belemnite Shales.

Surat, Broach and Rajpipla.—The Tertiary rocks in Surat, Broach and Rajpipla are practically confined to two small tracts, separated from each other by the alluvium of the river Kim, a small stream running to the sea from the Rajpipla trap area. The more southerly tract is the smaller, extending northwards from the Tapti for about ten miles, and being some fifteen miles across from east to west; the other area, between the Kim and the Narbada, stretches for about thirty miles from northeast to southwest, with a maximum width of about twelve miles. The rocks are nowhere well exposed and appear in discinnected outcrops chiefly in stream courses.[142] Occasionally the strata show appreciable disturbance, but the prevalent dip does not usually exceed 10° and is to the northwest. An anticlinal structure is recorded by Bose between Ratanpur and Damlai. Two series of beds can be made out, exhibiting a palaeontological contrast and separated from each other by an unconformity. The lower of these belongs to the Eocene while the upper is probably of either Miocene or Pliocene age.

Mr. Bose, whose observations refer to Rajpipla, describes the lower or Eocene series as one of gritstones and conglomerates with subordinate bands of clay, surmounted by a great thickness of clay beds containing thin intercalations of limestone which are in places very fossiliferous. The gritstone and conglomeratic beds with their bands of clay are well displayed in the Amravati stream between Ambos and Wagalkhar (*Waghulkhore*; *Vagalkhod*). The base is here a well marked conglomerate in which trappean pebbles are common. The clays, where exposed, are more or less ferruginous, assuming various tints of red and lilac and in places utilised as red ochre, elsewhere they have been converted into lateriate. Northeast of Surat the base is said to be made up of thick beds of ferruginous clay, with interstratified beds of conglomerate and limestone. Here also the clay, where exposed, assumes the brown pseudoscoriaceous crust characteristic of laterite, and is in all probability derived from the disintegration of the trap. These conglomerates contain agate pebbles also derived from the traps.

[140] Gen. Rep. Rec. 73, 83 (1938).

[141] Mary H. Latham, Proc. Roy. Soc. Edin., 59, pt. 1, No. 4, 47 (1938).

[142] P. N. Bose, Rec. 37, 174 (1908).

The limestones, sometimes nearly pure but more often sandy, argillaceous or ferruginous, in many cases abound in nummulites and other fossils; amongst them are:

FORAMINIFERA.

"*Nummulites ramondi* Defr." (probably the young form of *N. atacicus* Leym.)[143] (Laki and Kirthar),
Assilina exponens or *granulosa* (Sow.) or (D'Arch.) (Lower Kirthar, Meting limestone and Laki Limestone),
Discocylina dispansa (Sow.) (Middle Kirthar),
Nummulites obtusus Sow. (Kirthar).

LAMELLIBRANCHIATA.

Liostraea ("*Flemingostraea*") *flemingi* (d'Arch. & H.), (Laki and Kirthar).

GASTROPODA.

Rimella prestwichi d'Arch. & H. (Ranikot),
Vulsella legumen d'Arch. H. (Laki and Kirthar).
Ampullina (*Pachycrommium*) *flemingi* d'Arch. & H. (close to *Natica longispira* Leym. from the Lower Eocene of southern France),
Ampullospira (*Euspirocrommium*) *oweni* (d'Arch. & H.).

B. NORTHWEST INDIA.

Eocene of Tirah.—South of the Safed Koh in Tirah Mesozoic beds are succeeded by the Eocene which consists of:

3. Grey limestone.
2. A great thickness of greenish and red shales, with buff-coloured sandstones and subordinate limestone bands;
1. Nummulitic limestones, overlying.

The lowest of these subdivisions is perhaps the Dunghan Limestone, while the shales above are in all probability the Ghazij Shales.

North of the Samana range, in the Maidan valley, Eocene rocks are exposed in a narrow band not more than 700 feet wide; they are best seen in the low saddle between Maidan and Waran, striking E.—W., with a high dip from 60° to vertical.[144] Eastwards this belt extends for some distance but to the west it soon becomes covered by alluvium; it is however, found again between Guldast and Bagh and also to the southwest of Bagh. On the Tseri Kandao these beds form a sharply folded syncline, their base being visible in the southern limb but concealed in the northern by overthrust Cretaceous. The Eocene of this area consists at its base of a grey, calcareous sandstone, flaggy and thin-bedded, the lower portion of which contains in places a thin but well marked conglomeratic layer with small rounded fragments of the underlying pale grey limestone. The sandstone passes up into 150 feet of brownish red, finely laminated, unfossiliferous needle shale, which is overlain by shaly

[143] Rec. 59, 124, 1926.
[144] H. H. Hayden, Mem. 28, 99 (1900).

limestone containing many fossils, chiefly unidentifiable lamellibranchs and echinoid spines. The upper portion of this limestone is composed almost entirely of the remains of *Ostraea.* Above the oyster bed succeed another few feet of red shale, the upper portion of which is highly calcareous and contains Nummulites. Finally, upon this lies a bed, some 200 feet thick, of dark grey, compact, nummulitic limestone, composed of large numbers of small Nummulites; at the base of the limestone is a crushed shaly band containing larger Nummulites, some of them over an inch in diameter. The following is a generalised section of these rocks:

a. Nummulitic limestone, passing through shaly limestone with Nummulites down into

b. Reddish shale, about 10 feet thick;

c. Shaly limestone with an oyster bed at the top;

d. Reddish-brown needle shales, about 150 feet thick;

e. Calcareous sandstone, conglomeratic at the base, about 100 feet thick;

In the neighbourhood of Ghazni Tertiary rocks overlap in all probability both Palaeozoic and Mesozoic. Eocene limestone and shales form the hills over which the passes of the Kotal-i-Arda and Kotal-i-Dakai lead from Kharwar into Shilghar. Here they overlap the metamorphics and are cut off from the Mesozoic exposures to the southeast by the great Safed Koh fault.[145].

In south Afghanistan the Eocene is described as seldom less than 5,000 or 6,000 feet in thickness, rising in places probably to 9,000 feet or more; [146] here it includes the Dunghan Limestone.

The Eocene of Rajputana.—In northern and western Rajputana Nummulitic rocks emerge from the sands of the great Thar desert south of Bikaner and also to the northwest of Jaisalmer. In Jaisalmer the beds overlie the Abur group and form a conspicuous scarp stretching past the Parihar hills, and diminishing in the thickness eastwards; from 100 feet they decrease to about 50 feet, while the lowest in the reduced section at Khewalsir are said to be stratigraphically higher than any in the Abur scarp further west.[147] Associated with the Nummulitic beds, which are overlain by a ferruginous laterite, is a bed of very fine-grained unctuous clay or Fullers' earth; this clay is present also in the Bikaner inlier.

The Eocene of Bikaner comprises a variety of sediments including soft, white, sugary sandstones tinged with pink and red, purple quartzites surprisingly hard for Tertiary rocks, layers of ironstone whose debris is widely strewn over the country, Fullers' earth with well preserved marine lamellibranchs, white nummulitic limestone, and thin bands of lignite.[148]

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[145] C. L. Grieshbach, Rec. 25, 77 (1892).
[146] W. T. Blanford, Mem. 20, 149 (1883).
[147] R. D. Oldham, Rec. 19 159 (1886).
[148] Gen. Rep. Rec. 73, 26 (1938).

The Eocene of this region is of Laki age and has yielded *Ostraea multicostata* Desh., *Nummulites atacicus* Leym. and *Assilina granulosa* d'Arch.,[149] all obtained from a boring sunk for coal at Palana.[150] The coal, which is dark brown in colour, of a woody texture and does not soil the fingers, contains strings of iron pyrites. It lies immediately underneath the thick band of nummulitic limestone; some distance below it occurs the band of unctuous clay known as "Multani Mitti".[151] This clay, an edible clay, shows impressions of gastropods and foraminifera and is the result of a process of leaching.[152] The coal is interesting as being the only seam in India whose upper surface shows erosion and is unconformably overlain by newer strata.[153] An echinoid cast from the Eocene encountered in a well-boring at Madh has been identified as one probably allied to *Metalia sowerbyi.*

A limestone near Bilara in Marwar was found to be bituminous.[154]

The Palaeocene and Eocene of Kohat.

The northern extension of the Sulaiman range has not yet been examined geologically, but there is good reason to suppose that the fringe of Siwalik and other Tertiary rocks is continuous with the wide belt of Tertiary deposits, stretching from the northwest corner of the Punjab along the outer edge of the Himalaya to the border of Nepal.

General considerations.—The Palaeocene-Eocene formation is an important one in northwest India, though the immense thickness totalling 7,000-8,000 feet recorded by Wynne—at Bangasht in Kohat —is a serious exaggeration due to repetition by folding. From the observations of Col. Davies the Ranikot-Laki-Kirthar succession scarcely ever exceeds 1,000 feet. The Kirthar sequence, if we include therein the Lower Chharat beds, is about 600-700 feet; it and the Laki may locally attain a total of 1,000 feet. Wherever the Ranikot is present, the Laki and Kirthar are never very fully developed.[155]

The Kohat Salt Fields.—The lower Tertiaries of the Kohat district exhibit some peculiarities not observed elsewhere. The Eocene rocks are well developed in this region but their stratigraphical details have been worked out only in one or two isolated areas. Wynne's scheme of classification was as follows:—

		feet.
Nummulitic limestone	Limestone with some shaly bands . .	60-100

[149] Its megalospheric forms, *A. leymierie* d'Arch. & H. has also been identified in material from Jaisalmer (Gen. Rep. Rec. 73, 23 (1938).

[150] E. W. Vredenburg, Rec. 36, 314 (1907).

[151] T. H. D. La Touche, Rec. 30, 123 (1897).

[152] C. S. Fox, Mem. 57, 268 (1931).

[153] Mem. 57, 76 (1931).

[154] L. L. Fermor, Rec. 36, 126 (1907).

[155] Private Communication from Col. L. M. Davies.

Red Clay Zone	Red Clay, lavender coloured near the top, occasionally with nummulites; lower portion of the red clays in places partly or wholly replaced by fossiliferous sandstones, thick greenish clays and bands of limestones, all containing nummulites . .	150-400
Gypsum	White, grey or black gypsum with bands of clay or shale	50-300
Rock Salt	Thick salt beds, almost pure (base not seen)	300-700

The region under consideration is the hilly tract north of the Bannu plain and of the Chichali hills, and extending from the Indus on the east to the Kurram river on the west, a distance of 90-100 miles. The ground is traversed by a series of E.—W. ranges, formed chiefly of crushed, twisted and broken anticlines of the nummulitic limestone and associated rocks. This system of strike ridges and intervening plains fringes the mountainous country of older rocks to the north, from which it is separated by the boundary thrust-fault seen at the base of the Nilabgarh range north to Panoba.

The rock salt at the base of the Tertiary is of considerable economic importance, the average annual output during the quinquennium 1929-1933 amounting to nearly 21,000 tons. It consists of a more or less crystalline material nearly always grey in colour, with transparent patches (*shishinimak*), and never reddish like the salt of the Salt Range;[156] the grey colour is attributed by Murray Stuart to the presence in the salt of iron sulphide.[157] A few earthy bands occur, but the proportion of the whole mass too impure for industrial purposes is but small. Except where the salt is very massive and crystalline, its stratification is generally well marked; in the western exposures the lines of bedding are frequently as clearly seen as in any other stratified rock and determine the local method of working.[158] The salt is described by Murray Stuart as strikingly schistose, the schistosity increasing from east to west. No attempt is made to refine the salt which is marketed in the form in which it is mined. The quantity available is astounding. In the anticline near Bahadur Khel alone, rock salt is seen for a distance of about eight miles, the width of the outcrop being sometimes more than a quarter of a mile; here the thickness exposed exceeds 1,000 feet, a figure which, in the opinion of Murry Stuart, is exaggerated by repetition due to folding.[159] As a rule the salt is impregnated with sulphate of lime (gypsum) but not with the potassium and magnesium salts of the Salt Range beds; potash has been detected in the salt of Nandrakka (Nundrakki) and Kalabagh but only in the merest

[156] Although the distinction between the red salt of the Salt Range and the grey salt of Kohat holds good in general, Gee records the presence of both varieties in the Kalabagh area whose salt deposits are by universal consent correlated with those of the Cis-Indus Salt Range (private communication).

[157] Rec. 50, 62 (1919).

[158] A. B. Wynne, Mem. 11, 131 (1875).

[159] Rec. 50, 72 (1919).

traces.[160] Clean salt from Bahadur Khel has the following composition.[161]

	per cent.
Cl.	59.52
SO_3	1.50
CaO	1.06
Sodium	37.47
Insoluble	.45
	100.00

In some places the uppermost layer of the Salt is dark in colour, almost black, bituminous, with a smell of petroleum, and sometimes slightly pyritous. On dissolving some of the salt from Malgin, Dr. Murray Stuart obtained an appreciable quantity of gas, some bitumen and a trace of oil.[162] Usually the rock salt presents steep or vertical faces, a result of the rapidity with which it yields to the action of rain. By the latter also it is carved into pillars, spires, and strangely fluted or systematically grooved shapes. The ease with which it is eroded accounts for the broken, confused and irregular character of the anticlines whose cores it forms. In no case has the base of the deposit been seen.

At Jatta well preserved fossil leaves, probably of dicotyledonous type, have been noted by Gee in certain thin bands of soft clay and sandstone interstratified with the grey rock salt of the quarries.[163]

Above the salt come gypsum and clays, as in the Salt Range, but the colours—white and grey—are different, and the appearance of both the salt and gypsum is distinct from that of the Salt Range marl. It is not certain that the Kohat salt and gypsum are Eocene but, in the absence of any evidence to the contrary and in view of the apparent conformity with which beds either carrying Kirthar nummulites are associated with beds that do overlie the saline accumulations, the latter may be provisionally assigned to the Lower Kirthar.

The so-called Gypsum group occupies a large area and includes thick zones of greenish clay often containing plates of secondary gypsum (selenite) and sometimes carrying impressions of small grass-like plants. With these clays are also found thin, brownish, flaggy sandstones, some of them containing fossils, largely lamellibranch casts and small gastropods, and calcareous bands, some of them showing cone-in-cone structure caused perhaps by escaping gas during or soon after their deposition. Some of the shales are dolomitic and in the Malgin area have yielded a number of fossil fish of post-Creta-

[160] Gen. Rep. Rec. 49, 16 (1918).
[161] Mem. 11, 130 (1875).
[162] Rec. 50, 263 (1919).
[163] Gen. Rep. Rec. 68, 23 (1934).

ceous type.[164] Of these Dr. S. L. Hora refers one to the Clupeidae under the title of *Clupea geei*, another doubtfully to the family Dorosimidae, and two others to the order, Percomorphi.[165] The clupeid or herring is said to be the most predominant form and represented by a large number of fragments. This kind of fish is very gregarious and often enters estuaries in vast shoals; its remains, therefore if Dr. Hora's identification is correct, would suggest that the Saline series was laid down in a lagoon or bay, or estuary, or near a sea shore. Some of the shales are oil shales, one sample giving 38 gallons of crude oil per ton of shale.[166] Sometimes the flaggy sandstones are dolomitic and some of the calcareous bands are of foraminiferal limestone. The typical olive green clay bands are the same as those seen in the underlying rock salt stage, and the association between the latter and the gypsum stage is described as very intimate.[167]

The gypsum is very generally white in colour, but sometimes assumes a greyish, or less commonly a deep red hue; often in its parts it passes into black shaly beds smelling strongly of petroleum. The gypsum is for the most part pure and homogeneous, the only foreign matter sometimes visible being grey clay, crystals of iron pyrites, quartz, dolomite or anhydrite, and the bituminous ingredients of the black varieties. Associated with the gypsum in the east side of the district are one or more bands of black alum shale, so charged with pyrites as to be worked in a small way for sulphur.[168] Where the lamination in the gypsum is sufficiently distinct, it most frequently assumes complex folds resembling the contorted foliation of a gneiss.

With regard to the origin of the gypsum, leaving out of consideration a few cases where it is the product of the action upon limestone of sulphatic waters derived from the decomposition of pyrites, [169] some of the upper portions of the main gypsum zone are thought by Wadia and Davies to be of a secondary character produced as a result of concentrated solutions of magnesium sulphate in an enclosed lagoon acting upon the calcareous accumulations of nummulite tests during or immediately following their deposition on the sea floor; the presence of what are believed to be residual lenticles or "islands" of marl or dolomitic limestone in the midst of the gypsum masses is cited as proof of this suggestion.[170] Be this as it may, the bulk of the gypsum, as well as of the rock salt, may be regarded as chemically formed in a desiccating sea.[171]

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[164] From some part of the Eocene above the salt of southern Kohat comes the fish, *Capitodus indicus* Lyd. (Pal. Ind. Ser. 10, Vol. 3, No. 8, 245 (1886).

[165] Rec. 72, 186 (1937).

[166] Gen. Rep. Rec. 72, 54 (1937).

[167] Rec. 65, 114 (1931).

[168] For a description of the process employed see N. D. Daru. Rec. 40, 265 (1910).

[169] Murray Stuart, Rec. 50, 63 & 66 (1919).

[170] Trans. Min. & Geol. Inst. India, Vol. 24, 205 (1930).

[171] Mem. 40, 476 (1920).

In undisturbed sections, overlying the gypsum, there is found a thick belt of deep red clay, whose Eocene age is proved by the rare occurrence of nummulites in the upper portion. The bedding is sometimes marked by bands of slightly different tint, or by alternations of a more sandy nature which are sometimes flaggy and variegated with green spots; otherwise, signs of stratification are not well seen. Near the top of this group there frequently occur harder beds in the form of coarse purple sandstones, which in some localities are conglomeratic and contain small fragments of bone, and in others are replaced by bands of pisolitic haematite. These bone fragments and a few nummulites found near the top of the group in one locality are the only organic remains observed. Below, its members alternate with the gypsum, just as the latter beds appear to alternate in some places with the salt beds.

Above the "Red Clay Zone" come earthy limestones, clays and shales with nummulites. The main band of limestone is of no great thickness, and is massive, pale coloured and full of nummulites and alveolines. The overlying formation exceeds the Eocene in thickness and belongs to a later epoch known as the Murree.

The vicinity of Kohat town.—Linking up the above old and somewhat vague classification with that established further south has been made to some extent possible by two isolated sections described by Col. L. M. Davies in the light of more recent work; these are in the neighbourhood of Kohat town and at Bahadur Khel.

The representative of the great boundary fault passes along the foot of the Kohat Pass to the north of the town. To the north of this line of thrust, lies a mass of Mesozoic limestones and other rocks. The foothills to the south of it are occupied by E.—W. parallel ridges of nummulitic limestone, Kohat itself lying in one of the intervening valleys. The section, with its approximate equivalents, is as follows.[172]

Murree Series:

		feet	
	12. Sirki Shales (local outliers) up to . . .	30	Upper Kirthar.
Kohat Limestones	11. Hard, yellow, nodular limestone, with small nummulites and alveolines	60	Middle Kirthar.
Kohat Limestones	10. Flaggy or massive grey limestone, with larger nummulites and large assilines, which sometimes weather out dark red or by detritus)	520	Middle Kirthar.
	9. Nummulite Shale, the higher portion of which is darker in colour than the lower, containing many large specimens of *Assilina exponens* and packed throughout with *Nummulites atacicus* (*biarritzensis* type). *N. perforatus* (*crassus* type; ?= *N. obtusus* Sow.), *N. perforatus*, var. *obesa* (?=*N. obtusus* Sow.), *Alveolina*	130	Middle Kirthar.
	8. Kohat Shales. Pale yellow or white clay with subordinate calcareous bands, packed with Chamidae and other molluscs, and con-		Middle Kirthar.

[172] J.A.S.B., New Ser., Vol. 20, 210-214 (1924); slightly corrected in a private communication, 1939.

taining small echinoids and corals; ranging throughout are *Dictyoconoides kohaticus*, *Assilina spira*, *Alveolina oblonga* and *Discocyclina javana*	95	Middle Kirthar.
7. One or more bands of hard white or pale blue calcareous clay or limestone, sometimes showing sections of small Limnaeidae (*Planorbis*)	4-30	Lower Kirthar
6. Lavender-coloured clays, often interstratified with preceding, and sometimes replacing it	5-25	
5. Brown nodular clays, weathering to red or purplish colours (middle portion concealed by detritus)	520	
4. Hard, flaggy, yellowish-brown limestone, full of small nummulites; in the centre a bright ochreous band, 2 feet thick, with *Cidaris* plates and other fossils . . .	54	Laki Limestone
3. Shekhan Limestone. Alteranations of tough bands of lumpy limestone of pale yellow or white colour, with bright ochreous, clays, the upper middle part consisting of 18 ft. of hard, brown flaggy limestone; fossiliferous throughout, with *Nummulites atacicus*, *Assilina daviesi* de Ciz[173] abundant *Alveolina oblonga* and *Orbitolites complanatus*, also with large echinoids including *Conoclypeus pilgrimi*, *Hemiaster apicalis*, *H. digonus*, large corals (*Trochosmilia*, *Montlivaltia*, etc.) and large molluscs.[174] . .	146	
2. Soft, yellow and olive clays, may of them gypsiferous, with a few thin limestone bands including one in the middle of a bright yellow ochre colour	24	?Meting Shales.
1. Nodular, reddish-brown clays, weathering to a claret colour.	base not seen	

The seven lowest of the above subdivisions, which from their contained fauna probably represent the bulk of the Laki series, are not seen in the immediate vicinity of Kohat town but are best exposed, about four miles to the east thereof. Bed No. 2 has yielded traces of vegetable remains locally. From No. 3, the Shekhan Limestone which stands for the greater part of the Laki Limestone, Dr. L. R. Cox has identified.[175]

GASTROPODA.

Velates perversus (Gmel.),
Ampullina (*Pachycrommium*) *flemingi* (d'Arch. & H.),

LAMELLIBRANCHIATA.

Modiola daviesi Cox,
Lucina (*Pseudomiltha*) *vredenburgi* Cossm. & P.,

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[173] de Cizancourt, Mem. Soc. Geol. de France, N. S. 17, fasc. 1, Mem. 39, 23 (1938).

[174] L. M. Davies, Rec., 59, 362 (1926).

[175] Trans. Roy. Soc. Ed., Vol. 57, 25-92 (1934).

Spondylus radula Lam. (Europe, N. Africa, Bahrein Island and N. Persia), *Blagraveia sindensis* (d'Arch. & H.).

Bed No. 8, named by Col. Davies the Kohat Shales, has been divided by him into upper, middle and lower portions. The lower is distinguished by a small nummulites *Nummulites pinfoldi* Dav., closely allied to *N. beaumonti,* while its basal portion, which merges into the bed below (No. 7), is packed with a small *Ostraea* and the small *Assilina subpapillata* Nutt.; the middle has abundant mollusca and foraminifera but apparently no particularly characteristic species; in the upper, which contains molluscs throughout, are *Nummulites laevigatus, N. scaber, N. carteri, N. crassus* (*? obtusus*), *Assilina spira* and *Assilina exponens.* The aggregate fauna from the Kohat Shales is as follows :—

FORAMINIFERA.

Nummulites obtusus Sow., (*N. perforatus, or crassus*) type and var. *obesus,*
Nummulites laevigatus Lam.,
Nummulites scaber Lam.,
Nummulites atacicus Leym.,
Nummulites pinfoldi Dav.,
Nummulites carteri d'Arch. & H.,
Nummulites uroniensis Heim,
Dictyoconoides kohaticus Dav. (plentiful and typical of the zone; occurring in great numbers from the Jowaki border east of Kohat to Thal, at Bahadur Khel and many other places between Kohat and Latambar, and near Saidgi west of Bannu).[176]
Dictyoconoides kohaticus var. *spintangiensis* Dav. also on the Harnai-Spintangi lie in Baluchistan,[177]
Assilina spira de Roissy,
Assilina papillata Nutt.,
Alveolina elliptica (Sow.),
Alveolina elliptica var. *nuttali* Dav.,
Assilina exponens (?).

ECHINOIDEA.

Hemiaster cf. *digonus* d'Arch.,
Micropsis cf. *venustula* Dunc. & S.,
Eupatagus ["*Euspatangus*"] sp.,
Linthia sp.,
Porocidaris spines,
Leiocidaris spines.

ACTINOZOA.

Trochosmilia sp. (?)

LAMELLIBRANCHIATA.

Euphenax jamaicensis (Trechm.) Lutetian of Somaliland and Jamaica),
Ostraea (*Liostraea*) cf. *rouaulti* Mall. (forming a hard oyster-bed),
Chlamys wynnei Cox,
Spondylus perhorridus Oppenh. (Lawer Mokattam of Egypt).
Lucina (*Loripinus*) *kohatica* Cox.
Lucina (*Loripinus*) *pharaonis* Bellardi.
Meretrix cf. *sulcataria* (Desh).

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[176] Rec. 59, 240 (1926).
[177] Rec. 59 (1926).

Blagraveia sindensi (d'Arch. & H.),
Corbula (Bicorbula) subexarata d'Arch. & H.

GASTROPODA.

Velates perversus (Gmel.) (=*V. schmideliana* Chemn.),
Hippochrenes cf. *amplus* (Sol.),
Alaria (Digitolabrum ?) zigni (de Greg.) (Europe; Mokattam of Egypt),
Gosavia humberti (d'Arch. & H.),[178]
Involuta daviesi Cox.

This fauna was at first placed in the Laki, but is thought to have more in common with the Kirthar. It may be correlated provisionally with the Middle Kirthar, representing perhaps the lower portion of the Spintangi stage.

The Nummulite Shale (No. 9), a bed made up almost entirely of nummulite tests and one which we shall find again in the Punjab on the other side of the Indus, contains fragments of the large lamellibranch, *Gryphaea (Pycnodonta) brongniarti* (Bronn.)[179] sometimes accompanied by the small *Chlamys wynnei* Cox; otherwise mollusca are rare. Forminifera from this horizon include: *Nummulites obtusus* (Sow.), *N. uroniensis* Heim, *N. atacicus* Leym., *Assilina papillata* Nutt., *A. exponens* (Sow.) and *Orbitolites complanatus* Lam. The Nummulite Shale and the two succeeding beds which constitute the Kohat Limestones (10 and 11) represent part of the Middle Kirthar. These limestones have yielded the following foraminifera.[180]

FORAMINIFERA.

Lower (No. 10)	Upper (No. 11)
Nummulites obtusus (Sow).,	*Assilina rota* Dav.,
Nummulites uroniensis Heim,	*Assilina papillata* Nutt.,
Assilina papillata Nutt.,	*Dictyoconoides kohaticus*, var. *spintangiensis* Dav.,
Assilina irregularis Card.	*Nummulites obtusus* (Sow.),
	Nummulites uroniensis Heim.,
	Nummulites millecaput Boub.,
	Orbitolites complanatus Lam.

The nodular limestone, No. (11) is often found forming a ragged top to the foot-hills east of Kohat. It is at least part of Wynne's "Alveolina Limestone" but not the "Alveolina Limestone" of Griesbach and Vredenburg which is a term including both the Laki and the Meting limestones of Sind; Wynne may have included bed (10) under this designation. Beds (8) and (9) may stand for the bulk of his "Red Clay Zone", while beds (5) (6) and (7) may be the equivalents of his Salt and Gypsum zones. The correlation between the two schemes of classification, however, has not yet been properly worked out.

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[178] Omitted from the list on p. 28, but included on p. 58.

[179] Frequently spoken of a *Ostraea vesicularis* in literature on the Indian Eocene.

[180] L. M. Davies, Q.J.G.S., 96, 223 (1940).

Succeeding the Kohat Limestones are local outliers, never more than 30 feet thick, of shales which have yielded a distinctive fauna resembling that found in the uppermost levels of the Spintangi section in Baluchistan and regarded as of Upper Kirthar (Auversian) age ; to these shales Colonel Davies has given the name of Sirki Shales, named after the village of Sirki Pela (Private communication). Among the foraminifera found, Col. Davies has identified: *Assilina rota* Dav., *Assilina papillata* Nutt., *Dictyoconoides kohaticus*, var. *spintangiensis* Dav., *Alveolina elliptica* (Sow.). *A. elliptica*, var. *nuttalli* Dav., *Nummulites obtusus* (Sow.), *N. uroniensis Heim*, and *Orbitolites complanatus* Lam.

Bahadur Khel.—A somewhat analogous sequence has been recognised in the section at Bahadur Khel. Between the salt and the "Red Clay Zone" are 190 feet of olive shales and clays with yellowish limestone bands, forming the Gypsum group of Wynne. Kohat bed No. 5 is represented at Bahadur Khel by a thick mass of brick-red clays with sandstone bands. Beds 6 and 7 are also recognisable and with 5 make up the bulk of a sequence which is assumed to be the equivalent of the Lower Kirthar and which is here crushed out and much reduced. The Kohat Shales can not only be identified at Bahadur Khel but, according to Col. Davies, are of the same thickness, 90-100 feet, and are divisible into the same three zones, with *Nummulites pinfoldi* in the lower and the *Ostraea* band at its base, and *Nummulites laevigatus* and *N. scaber* in the upper. The complete fauna so far obtained from the Kohat Shales at Bahadur Khel is given as follows:—

FORAMINIFERA.

Nummulites obtusus Sow. (*N. perforatus* or *crassus*),
Nummulites laevigatus Lam.,
Nummulites scaber Lam., (?)
Nummulites atacicus Leym., (?)
Nummulites pinfoldi Dav.,
Dictyoconoides kohaticus Dav.,
Alveolina (*Discocyclina*) *javana* (Verb).

ECHINOIDEA.

Schizaster symmetricus Dunc. & Sladen.,
Eupatagus ("*Euspatangus*") sp.,
Metalia sp.,
Micropsis sp.,
Leiocidaris spines (?)

LAMELLIBRANCHIATA.

Euphenax jamaicensis (Trechm.).
Ostraea (*Liostraea*) cf. *rouaulti* Mall,
Lucina (*Loripinus*) *kohatica* Cox.
Balgraveia corrugata Cox,
Cardium halaense d'Arch. & H..
Cardium salteri d'Arch. & H.,
Cardium greenoughi d'Arch & H. (?)
Corbula (*Bicorbula*) *subexarata* d'Arch. & H.,
Panopea cf. *intermedia* (J. Sow.).
Fistulana elongata Desh.[1]

GASTROPODA.

Cepatia cepacea (Lam.) (Middle & Upper Eocene of Europe ; Mokattam of Egypt ; Middle Eocene of Asia Minor),
Natica epiglottina Lam.,
Velates perversus (Gmel.),
Oliva virginiae d'Arch. & H.,
Limbs of fossil crabs.

ACTINOZOA.

Trochosmilia sp.

In spite of the presence of two additional Laki forms, *Schizaster symmetricus* and *Natica epiglottina,* the beds are referred to the Kohat Shales.

Sections in the northwest corner of the district.—A few miles southwest of Fort Lockhart, between Shinawari and Kahi (Kai) Eocene beds are exposed in the form of sandstones interbedded with light coloured and greenish shales.[181] The type of the sandstones which are well seen in the small hill on which the village of Kahi stands. varies from a pale buff to a dark ferruginous rock, but weathering in nearly all cases, like the sandstone of the Tochi valley, to a black surface. These beds which may correspond to the Ghazij Shales are underlain southeast of Shinawari by olive and reddish brown shales containing locally thin bands of highly altered limestone.

At the western end of the tract of country now under consideration, the topmost zone of the Ranikot at Thal is uniformly succeeded by blue-grey clays which may represent the Lower Kirthar, these are overlain by limestones with a fauna which, although possessing several Laki forms, includes *Dictyoconoides kohaticus* (Dav.) and corresponds apparently to that of the Kohat Shales in the Kohat section, though less fossiliferous.[182]

Panoba.—Along the Afridi border country of the Kohat district, a well defined anticlinal dome of Eocene rocks has attracted attention by reason of some oil seepages at a small collection of farms in the hills known as Panoba. The anticline is a steep, compressed, slightly sigmoidal fold, with no crest remaining at its highest elevation, and with a general E.N.E.-W.S.W. direction. The southern flank is disturbed by a minor fold, and the eastern half of the anticline is slightly overfolded towards the south.[183] As the fold pitches, the crest makes its appearance, especially towards the east in which direction the pitch is gentle ; westwards the latter is abrupt, rising to as much as 35°. East of the Ungo Pass are two small domes echelonned on the Panoba anticline.

The lowest stage exposed, forming the core of the fold, is a grey limestone with traces of nummulites and belonging to the Palaeocene. This rock, probably the equivalent of the Khairabad Limestone of the

[181] H. H. Hayden, Mem. 28, 99 (1898).
[182] L. M. Davies, Q.J.G.S. Vol. 33, 264 (1927).
[183] E. H. Pascoe, Mem. 40, 412 (1920).

Punjab salt Range, is bituminous and is exposed to the extent of about 1,300 feet in an outcrop some 3¾ miles in length, forming the high ground in the centre. The beds which follow, traceable continuously round the central core, consist of thin, soft, sandy clays with alum and much carbonaceous matter: these beds correspond to the black shale at the foot of the Kala Chitta on the other side of the Indus, to the Patala Shales of the Salt Range, and to the coaly stage found in the Hazara district. Then come green shales with thin bands of limestone, perhaps the equivalent of the Nammal stage of the Salt Range,[184], followed by a limestone which has been equated with the Shekhan Limestone of the Kohat section and with the Sakesar Limestone of the Salt Range. Above come soft, sandy clays or shales, some reddish in colour, especially towards the top. with calcite, much gypsum and here and there sulphur, and thin bands of marl; in some of these beds sulphur pits used to be worked before the British Rule. These strata correspond more or less with the Lower and Middle Chharat sequence of the Potwar area, and with the Bhadrar beds of the Salt Range. The highest beds exposed include representatives of two of the beds seen at the top of the Chharat succession across the Indus, the lamellibranch bed and the Nummulite Shale with numerous *Nummulites atacicus*; the two. however, are mostly consolidated into a massive limestone.

Bannu.—Forty miles southwest of Bahadur Khel, Colonel Davies has recognised the Kohat Shales and the three overlying sub-stages (Nos. 9, 10 and 11) of the Kohat Eocene sequence in the limestone ridge.

The Palaeocene and Eocene of the Punjab and Hazara.

Relationships.—South of the Kohat salt fields is the Bannu plain, between which and the Indus alluvium intervene the arcuate ranges forming the trans-Indus continuation of the Punjab Salt Range. Before discussing the Eocene in these more southerly trans-Indus hills, it will be best to consider the cis-Indus Eocene of the northwest Punjab, commencing with the occurrences in the mountains of Hazara and northern Attock and the great Potwar plateau which stretches between them and the Salt Range in the south.

On the eastern side of the Indus the Eocene has been spoken of largely as the "Nummulitic series" and subdivided into Lower Nummulitic and Upper Nummulitic. This old classification, though convenient for lithological reasons, is unfortunate in that it does not correspond with the subdivision of the Eocene in western India. The Lower Nummulitic, for instance, little as we know about it, is not confined to the Lower Eocene but includes part at least of the underlying Palaeocene; the Upper Nummulitic, far from being the equivalent of the Upper Eocene, is roughly equivalent to the Lutetian (Middle Eocene) and Auversian of Europe. The term "Hill Limestone" or "Hill Limestones" derives its origin from the prominent

[184] Gen. Rep. Rec. 69, 71 (1935).

part these beds take in the formation of the outer ridges of the Hazara mountains, the Kala Chitta hills and the plateau-like summit of the Salt Range. The term has been used considerably and somewhat vaguely for the massive limestones which make up the bulk of the Lower Nummulitic; occasionally it seems to have been employed as a synonym for the Lower Nummulitic as a whole. In general the Lower Nummulitic group consists chiefly of massive limestones interbedded, especially in the lower portion of the formation with subordinate beds of dark shale, variegated sandstone and local coaly beds. For the lower portion of the "Upper Nummulitic" Mr. Pinfold has proposed the term "Chharat series", named after a village near Fatehjang where these beds are best displayed.

The Kala Chitta Hills.—The Lower Nummulitic is well exposed in the Kala Chitta range in the Attock district, in the Margala hills to the northeast, and in the "Nummulitic zone" of the Hazara-Rawalpindi border country.

The principal rocks exposed in the Kala Chitta are the Lower Nummulitic, including the so-called "Hill limestones", contorted by compression, and thrust southwards over the Muree rocks of the foot-hills, along one of the "boundary" faults of the region. Eastwards, near Golra, the range sinks to the general level of the foot-hills, becomes simpler in structure and finally tails off in a narrow anticline of Upper Nummulitic strata.[185] Westwards this Nummulitic outcrop stretches across the Indus into Kohat where it follows a course to the north of the salt fields. The maximum thickness of the Lower Nummulitic in the Kala Chitta is difficult to estimate on account of the compression to which it has been subjected, but is thought to be between 1,600 and 1,700 feet, much of which belongs to the Palaeocene.

The lowest horizons recognised in these hills are exposed north of Domel, west of the railway, and have yielded Upper Ranikot fossils.[186] According to Col. Davies (private communication) the sequence here is as follows:—

	Feet
(3) Alternating shales, sandstones and thin bands of limestone, the first and last usually fossiliferous	400
(2) Fossiliferous limestone	80
(1) Fossiliferous, yellow shales (base not exposed)	200

The following are the fossils from these beds, with their range:—

FORAMINIFERA.[187]

Nummulites nuttalli Dav., Upper part of (2)
Nummulites sindensis Dav., Upper part of (2)
Nummulites globulus Leym., (1) only; rare.
Assilina dandotica Dav., Uppermost parts of (3)
Operculina cf. *canalifera* d'Arch., (3).
Operculina salsa Dav., (3).

[185] C. S. Middlemiss, Rec. 49, 140 (1918).
[186] Pal. Ind., New Ser., Vol. 24, No. 1, p. 3, note (1937).
[187] Col. L. M. Davies.

Operculina subsalsa Dav., (1) and (3),
Operculina patalensis Dav., Lower parts of (3).
Miscellanea miscella (d'Arch. & H.), From base of (1) up to the middle of (3),
Miscellanea stampi Dav., Upper part of (2) and Lower part of (3).
Lockhartia haimei (Dav.) Throughout the whole sequence.
Lockhartia newboldi (d'Arch. & H.) Throughout the whole sequence.
Lockhartia conditi (Nutt.), Throughout the whole sequence.
Lockhartia tipperi (Dav.), Throughout the whole sequence (a form recognised in the Lower Eocene of Somaliland),
Lepidocyclina (Polylepidina) punjabensis Dav., From the base of (1) up to the lower part of (3),
Discocyclina ranikotensis Dav., Lower part of (3) ; uncommon.
Alveolina vredenburgi Dav., Upper part of (2).

OSTRACODA.[188]

Bairdia subdeltoidea (Munst.) Throughout the whole sequence.
Bairdia cf. *contracta* Jones (3) near top.
Cythereis ranikotiana Lath. (3),
Cythereis mersondaviesi Lath. (1) and (3).
Cythereis bowerbanki Jones (1) and (3).
Bythocypris subreniformis Jones & Sherb (3).

The top of the 80-feet limestone (2) is correlated by Davies with the top of the Khairabad Limestone of the Salt Range, and the 400 feet of overlying sediments (3) with the Patala Shales of the same area, excluding the uppermost zone of *Nummulites lahirii* which has not yet been observed in the Kala Chitta. Subdivision No. (1) probably corresponds to part of the nammal stage of the Salt Range sequence.

In many parts of the range, the base of the Lower Nummulitic is a pisolitic ferruginous band, from 1 foot to 5 feet in thickness; it is one of the several lateritic layers of terrestrial character found in the Eocene of western India, and may be that at the base of the Laki, as suggested by Cotter,[189] or at some low horizon of that series.

In the small Kawa Gar range immediately south of the town of Campbellpur, there intervene between the Mesozoic complex of Kioto and Gimul rocks and the band of ferruginous pisolite some shales which are thought to form an integral part of the Palaeocene-Eocene succession. These shales, which are twisted and crumpled along their lower boundary but are undisturbed where they are in contact with the Hill Limestone which succeeds them, are of a light blue colour with buff partings and jointings, and break into small cubes and sharp-edged fragments; included in them are thin layers of hard, fine-grained, calcareous sandstone. At one locality a further 12 feet of strata, in the form of buff, nodular, sandy limestone, succeed the shales—here themselves marly and nodular—and are capped by 6 feet of haematite shale, the local representative of the ferruginous pisolite. A few miles further east, near Hassan Abdal, shales are again seen underlying the Hill Limestone, but these are dark blue

[188] Miss M. H. Latham, Proc. Roy. Soc. Edin., 59, pt. 1, No. 4, 46 (1958).
[189] Mem. 55, 93 (1933).

or black and contain nummulites and the ferruginous pisolite is absent.

The basal ferruginous bed in the Kala Chitta is followed typically by from 5 to 10 feet of a loosely compacted, rough, saccharoid sandstone, glistening white, pinkish white, deep reddish purple, or a variegated alternation of these tints. Locally this bed appears to have been replaced by a hard, compact, white shale with pink staining, or by a crushed, friable limestone conglomerate or breccia. In Hassan Abdal hill the ferruginous pisolite, which is present, is followed by 60 feet of a soft, nodular, creamy limestone which has yielded an *Echinolampas* akin to *E. lepadiformis*, a Laki species ; most of this would seem to belong to the zone described in the next paragraph.

The pisolitic band and variegated sandstone are not always present, but wherever they are seen they are followed by a zone of limestones, blue or creamy blue in colour and mottled, like the Triassic limestone they resemble, with buff and ochre ; no fossils have so far been obtained from them. With a maximum of 250-300 feet the thickness varies considerably, and in some sections these beds, which form the base of what have been called the " Hill limestones ", seem also to have been pinched out with the pisolite and variegated sandstone, or are represented by unmottled limestones of the normal type. The next beds seen are concretionary limestones containing nummulites, among which a species assigned to *Assilina granulosa* is conspicuous, and other fossils in a fragmentary condition. These concretionary limestones consist of irregular lumpy layers separated from each other by thin shale partings which are frequently carbonaceous : a thin greenish sandstone is sometimes seen interbedded in the limestones. To this horizon probably belong some beds seen a few miles southwest of Campbellpur, consisting of 100 feet of gypsiferous shale interbedded with nummulitic limestone ; these beds contain thin layers of carbonaceous shale and, throughout a thickness of a little over 2 feet, lenticles of coal. The beds so far mentioned may correspond to the Salt Range stage known as the Nammal stage of Limestones and shales, which is typically Laki.

The rest of the Lower Nummulitic in this area is made up of bands of massive limestone separated from each other by belts of these concretionary limestones with their shale partings. These beds are probadly the equivalents of the Sakesar Limestone. The massive bands are sometimes very thick as for example that forming the ridge north of Chak Dalla, which is something like 900 feet thick, forming a prominent feature westwards, curving sharply round at the pitch of the anticline and again producing conspicuous heights and waterfalls along the margin of the plain. The Hill limestones are grey to bluish grey in colour, sometimes with ochreous blotches, and emit a fetid odour when broken. An occasional thin-bedded ochreous variety with lamellibranch fragments recalls the Giumal type. There is no regular jointing in the Hill limestones but the bands are frequently much cracked, the cracks being filled with calcite. The rock weathers in a

characteristic way; numerous points in it being more resistant than the rest, sharp edges separated by shallow curved channels are produced, the latter resembling those made by a blunt cheese-scoop. It exhibits occasional sections of gastropod and lamellibranch shells and in places faint traces of nummulites. In the more westerly parts of the range, in addition to *Assilina granulosa*, traces of what are probably *Alveolina* and *Textularia,* together with *Lucina* sp., *Conoclypeus* sp. and *Isis* sp. have been reported.[190]

The Chharat stage (Upper Nummulitic) is seen along the southern flank of the Kala Chitta, below the boundary fault, (see p. 1540) and possibly also in the centre of the range itself to the north and north-west of Fatehjang. It also occurs in one or two of the small hills immediately north of this part of the range; south of the village of Shahpur, which is about 4½ miles north of Fatehjang, the facies is somewhat more arenaceous, thin reddish sandstone beds being intercalated with the variegated shales.

In the Chalk Dalla section of the Kala Chitta, some thin doubtful beds, including a bleached splintery limestone, immediately north of Samul Khankah, may possibly belong to the Chharat stage, and coincide closely with the horizon of the oil seepage of this locality.

Peshawar.—In the southern part of the Peshawar district, the rugged cliffs of the Cherat ridge are occupied by the northern limb of an anticline which strikes E.N.E.—W.S.W. and has lost the rest of its integrity by strike faulting; the fractured southern limb is now covered by a mass of Recent deposits, to the south of which is a wide stretch of Upper Tertiary. The oldest bed exposed in the ridge is a limestone of possibly Jurassic age. This is succeeded by shales and sandstones which may represent the Cretaceous. Above them comes a massive bituminous limestone which Coulson correlates with the "Hill Limestone" of the Punjab on the one hand, and with the Dunghan Limestone of Baluchistan on the other. It forms the main part of the Cherat ridge, and foundered parts of the anticlinal crest are composed thereof. The rock contains abundant foraminiferal remains, none of which has so far been identified, [191] these and the shells of bivalves are conspicuous on weathered surfaces of the rock. The Dunghan Limestone is succeeded by a series of beds which are thought to represent a part at least of the Chharat series and appear to follow conformably upon the Dunghan, though the inter-relationship is obscured by overfolding and faulting. These higher beds consist of grey and greenish grey, splintery, marly shales, associated with beds of ferruginous sandstone and concretionary marl; in addition are subordinate and lenticular beds of grey limestone, some of them of an algal nature and containing unidentifiable fossils. This higher stage is comparable with Griesbach's Dag beds; the thick bed of grey earthy limestone underlying them at Dag has yielded nummulites.[192] Coulson failed to recognise the Nummulite Shale in

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[190] Mr. H. M. Lahiri records a nummulite which he doubtfully refers to the Ranikot species, *Assilina ranikoti* Nutt.

[191] Rec. 63, 84-85 (1930).

[192] Rec. 25, 96 (1892).

the Eocene succession of this area, the higher beds being followed by typical Murree sediments.

In the Nalabgarh range to the east the Nummulitic formation occupies a tract some two miles in width, but the beds are repeated in several folds.

Hazara.—At the eastern end of the Kala Chitta, about five miles farther north, another limestone anticline rises *en echelon* eastwards to form the Margala hills and is likewise overthrust southwards on to younger rocks. Both the Kala Chitta and the Margala outcrops are part of the Broad belt of Eocene and Mesozoic rocks which continues north-eastwards along the mountainous country forming the borderland between the Hazara district of the North-West Frontier Province and the Rawalpindi district of the Punjab, to the vicinity of the Jhelum river.

Of the zones of disturbance into which the Hazara region has been divided by Middlemiss, that occupying this strip of mountainous country consists very largely of Eocene rocks through which protrude long narrow outcrops of Mesozoic beds exposed along fractured anticlines. This "Nummulitic zone" is sharply defined from the "Slate zone" to the northwest, and from the "Upper Tertiary zone" of the lower hills on the southeast, by overthrust boundary faults. This simple arrangement, however, has been complicated by a repetition *en echelon* of the inner boundary fault. This repetition, which is an adjustment caused by the approach to the obstructive syntactical point of Muzaffarabad, is responsible for the large exposure of Eocene and Mesozoic rocks which commences south of Abbottabad and extends for 15 or 16 miles towards the Jhelum in a northeast direction, and lies abnormally in the "Slate zone".

The topography of the "Nummulitic zone" is characterised by the parallelism of the main valleys to the general strike of the country, which is in most place W.S.W.-E.N.E. but swings elsewhere to S.W.-N.E., and by an absence of outliers and isolated hill masses. Within this belt lie the well known "gulees" (*galis*) or valleys, the objects of many an excursion from the hill station of Murree.

Omitting 300-400 feet of well bedded grey limestone, which was at one time tentatively placed at the base of the Nummulitic sequence of this region, but which seems more likely to belong to the Cretaceous, the lowest Eocene exposed in Hazara and northern Rawalpindi consists of the variegated sandstone and clays with coal, varying from 2 to 20 feet thick. The same sugary texture is characteristic, and the basal portions are sometimes conglomeratic. The coal and carbonaceous bands are found more especially in those Eocene outcrops which lie within the "Slate zone"; the thickest section of these beds is about 17 feet, but in most cases they have been crushed and squeezed into one another and no true sequence is visible.

Next follow 200 feet of well bedded massive limestones, always slightly concretionary, generally black-hearted and of foetid smell when freshly broken.[193] Nummulites and other foraminifera, mostly of very small dimensions, may be seen in the rock in swarms or colonies, usually grouped around the imperfectly formed concretions. Along the southern borders of Hazara this limestone is described as more markedly concretionary. Middlemiss correlates these limestones with *Echinolampas* zone in the hill near Hassan Abdal.[194] They appear to be the only representatives of the " Hill limestones " and to conclude the Lower Nummulitic sequence, for the shales which are said to follow are more likely part of the Upper Nummulitic or Chharat stage ; the stratigraphical position of the shales, however, must remain doubtful until their foraminifera have been identified.

In the Hazara hills, the Chharat stage is undoubtedly represented by the Kuldana beds of Middlemiss. There are, however, in this area about 300 feet of grey splintery shales and marls interbedded with black-hearted, nodular or concretionary limestone, carrying nummulites. These beds are recorded by Middlemiss as occurring between the massive limestones which we have correlated with the " Hill limestones " and the Kuldanas ; whether they belong to the Lower or to the Upper Nummulitic is a question for further investigation. Of these beds the shales and marls are described as exceedingly splintery and varying in colour from pale to dark grey. The limestones vary from place to place but on the whole occur in comparatively thin layers. This zone is described as much more fossiliferous than the beds below, the nummulites being much larger.[195] A band of corals, with a species of *Montlivaltia* in great numbers and very well preserved, occurring on the southern craggy face of Sirban hill, is assigned to this zone.

The Kuldana beds[196] are the equivalent of the variegated shales, zone 2, of the Chharat section in the Potwar area, the outcrops of the two formations having been traced continuously, except for the intervention of the Hazara fault, from one region to the other. They have yielded no specimens of *Planorbis* itself but Pinfold found in them small shells suggestive of *Limnaea*. The only feature in which they appear to differ from the Chharat zone 2 is the inclusion among the beds of fine sandstone. The deep inky purple or chocolate brown colour of the Kuldana beds forms a noticeable feature in the landscape, and stain whole hill-sides with their dark reddish debris.

The Potwar Plateau.—In the Potwar plateau E. S. Pinfold has extended the system of structural ones established by Middlemiss in

[193] C. S. Middlemiss, Mem. 26, 41 (1886).

[194] Probably from these beds come the nautilus named by H. C. Das Gupta *Nautilus hazaraensis* (close to *N. forbesi* d'Arch & H), and found near Kuthwal (J.P.A.S.B., New Ser., Vol. 11, 256 (1916)) ; the same authority records a ponted coral from Hassan Abdal.

[195] C. S. Middlemiss, Mem. 26, 42 (1896).

[196] At first thought to pass up into the Murrees and later confused with the basal Murree bed known as the Fatehjang Zone (see E. H. Pascoe *Mem.* 40, 335, 345-6 (1920)).

the Hazara country. Middlemiss' "Upper Tertiary zone", the successor southwards of the "Nummulitic Zone", coincides with Pinfold's "Isoclinal zone". South of the latter which is some 12 to 20 miles in width, is the "Fault zone", the boundary between the two zones being the strike fault which crosses the Indus west of Jand and can be traced for over 40 miles continuously eastwards to the southern border of Khair-i-Murat ridge, southwest of Rawalpindi. The general structure characterising this fault zone is that of a series of open synclinal basins separated from each other by faulted anticlinal saddles; four of these strike faults, including that which joins Jand and Khair-i-Murat, have been traced westwards to the Indus.

The nearest Nummulitic exposures south of the Kala Chitta occur in the "Isoclinal Zone" west of Fatehjang, around the village of Chharat, where the upper division is well exposed. This area has attracted the notice of travellers on account of its well known oil seepages. The total thickness of the Upper Nummulitic or Chharat stage, as it has been here so called, in this and other parts of the Potwar, varies from about 500 to 900 feet.

Chharat lies on the crest of an E.-W. anticline with minor puckers on its flanks. The fold extends westwards for two miles and then assumes a W.N.W. direction; past Banni Fateh Khan it splits into two and finally four folds the most northerly of which is disturbed by the thrust fault which defines the true limits of the Kala Chitta range.[197] Eastward from Chharat it bifurcates and twists in a complicated way. The beds frequently show contortion and minor reversed faults are characteristic of the structure.

The lowest beds exposed consist of grey limestone, in places containing a few nummulites but usually unfossiliferous, and belonging probably to the Lower Nummulitic division. Above this is the Upper Nummulitic which is succeeded unconformably by the Murree series. The Upper Nummulitic was subdivided by Mr. Pinfold into four groups, the complete scheme of subdivision being as follows:

Murree series.

Upper Chharat.	4. Nummulite Shale.
	3. Thin-bedded limestones and green shales, (Kohat Shales).
Lower Chharat	2. Variegated shales with bleached marl and limestone bands.
	1. Passage beds of chalky gypsiferous limestones, with ochreous layers, passing down into the more massive limestones of the Lower Nummulitic

From the passage beds come the main oil seepages, not only in this area but in other areas such as Golra, Ratta Hotar, etc. Small crystals or thin plates of sulphur occur in the more shaly layers of these limestones. This subdivision belongs either to the basal Kirthar or the top of the Laki.

These basal strata are succeeded without any break or lithological change by the next sub-stage. The shales are brightly coloured,

[197] E. H. Pascoe, Mem. 40, 373 (1920).

varying from reddish purple to indigo and green, the purple variety being identical in appearance with that so typical of the Murrees. They include beds of fibrous gypsum, which are especially abundant in the lower parts of the group. The marl and limestone bands also become somewhat thicker towards the base, their colour, which in the higher bands is dark, becoming at the same time lighter. Pinfold estimates the thickness of the sub-stage at 300-500 feet.[198] Vertebrate remains, mostly of *Gavialis* and chelonian plates, have been collected from the shales and are distinguishable by their highly glazed surface.

These, together with specimens of *Planorbis*, often found in considerable abundance in the limestone bands, prove that the beds are fresh-water or brackish-water in origin and were laid down under premature Murree conditions. The massive beds of white opaque gypsum, on the other hand, if rightly regarded as of sedimentary origin, indicate waters saturated with brine. The deposits of gypsum are local and usually not more than two or three feet in thickness, but flakes of selenite of secondary origin are common in the variegated shales. The bleached marls and limestones are thin and split into splinters at right angles to the bedding, the result being a very characteristic untidy surface, littered with broken angular fragments of all sizes and usually very bare of grass or bushes. This zone is the approximate equivalent of Wynne's "Red Clay zone" to the west of the Indus, and of part of the Ghazij shales of Baluchistan. It also corresponds to sub-stages (7) and (6) and at least the bulk of (5) in the Kohat sequence, the first of which has yielded *Planorbis*.

Following the above beds is a nodular, concretionary limestone crowded with fragments of marine shells, most of which are indeterminable. Other thin-bedded white limestones of this zone (No. 3), which is from 100 to 200 feet thick, also contain abundant casts of lamellibranchs and gastropods, some of the beds being packed with a small thin-shelled *Ostraea*, a large thin-shelled species of the same genus is less common. The green shales are for the most part barren of fossils but contain small nummulites in their uppermost horizons. We have here another example of the rapid alteration of fresh-water, salt-lake and marine conditions, which characterised much of the Eocene period in western and northwestern India. This zone is the equivalent of the Kohat Shales.

The uppermost zone is a band consisting almost entirely of nummulites. The rock varies from a loose gravel with very little interstitial clay, to a more or less compacted conglomerate, the hardness and coherence of which depend upon the degree to which the interstitial matter has been reinforced with carbonate of lime at the expense of some of the nummulites. Where this has taken place to a maximum extent, the result is a uniform limestone totally devoid of texture and recognisable nummulites; in this form it differs inappreciably from the Hill limestone of the Lower Nummulitic. The two predominant nummulites are the large flat *Assilina exponens* and the small globosa *Nummulites atacicus*, in addition to which

[198] Rec. 49, 144 (1918).

Nummulites obtusus (="*N. perforatus*" and *Assilina papillata* have been identified;[199] the only other fossils are the thick-shelld, globose *Gryphaea* (*Pycnodonta*) *brongniarti* (Bronn), very generally occurring with valves united, and its usual accompaniment, the small *Chlamys wynnei* Cox. The ostracod, *Cythereis bowerbanki* Jones, has been found in this bed in the Bhagwan Kas.[200] This characteristic bed, with a thickness varying from 50 to 100 feet and sometimes more, is extraordinarily persistent amid the distortion and fracture and is extremely useful in elucidating the structural details of the folding. It is the highest marine bed found in this part of India, the Kohat Limestone of the Kohat succession not having been recognised as such. The Nummulite Shale is said to resemble certain beds of the Spintangi limestone near Sukkur and in Baluchistan where, the bed, although sometimes loosely compacted, usually has a calcareous matrix, in one horizon near Sukkur, the same nummulites are associated with the same gloose oyster.[201]

The Chharat stage occupies a long belt along the southern base of the Kala Chitta hills, and over it is thrust the Lower Nummulitic. Whether there is an uninterrupted succession of the Chharat beds here is doubtful. The least discordant section of the stage occurs northwest of Mahura, where it occupies a maximum width of outcrop, the lowest eds consisting of black carbonaceous shale. Here thick masses of stratified gypsum are seen, and thin limestone bands are found especially near the top. The limestones are typically nodular but, west of Mahura, are thicker and more continuous, resembling bands in the Lower Nummulitic; fragmentary fossils are not uncommon and the highest band is crowded with lamellibranch and gastropod shells, all of them much broken. This limestone zone is conspicuous near Jhalar and between Samul Khankar and Mahura where some of the bands are more of the nature of calcareous sandstone. The Nummulite Shale, with its *Nummulites atacicus* and *Assilina exponens*, caps the stage; immediately north of Mahura it is in contact with the Chharat red shales, the limestones being locally wanting.[202]

This outcrop of the Chharats extends westwards with scarcely any interruption past Chab to the Indus and beyond. Several other long narrow outcrops of these beds—especially of the uppermost zones—are seen exposed in the Murree tract to the west and southwest of Chab.

The Khair-i-Murat ridge, one of the most conspicuous features in the northern part of the plateau, coincides with an outcrop of Hill limestone, stretching from the village of Murat southwestwards in a sinuous line 15-16 miles in length to Galli Jagir. Half-a-mile further west Nummulitic beds, belonging entirely to the Upper

199 Gen. Rep. Rec. 62, 157 (1929).

200 Mary H. Latham, Proc. Roy. Soc. Edin., 59, pt. 1, No. 4, 47 (1938).

201 E. S. Pinfold, Rec. 49, 145 (1918).

202 E. H. Pascoe, Mem. 40, 387 (1920).

division, again appear from beneath the alluvium in a smaller ridge, nearly but not quite in the same line of strike, and extend in the same general W.S.W. direction for at least another 5 miles past Dhok Maiki. The crest of the ridge, which is never once broken through by a stream, is curiously level, extending most of the way some 1,000 feet above the plain below. The structure is that of a broken anticline exposing Nummulitic beds, thrust southwards over the Murrees and flanked normally but unconformably by the same younger series along its northern limit. About a mile due east of Murat is a very small exposure of Upper Nummulitic, and about another mile in the same direction, in the Sil river, is yet another. Neither of these outcrops strike in line with the rock of the main ridge.

Nearly the whole of the main ridge consists of Lower Nummulitic limestone of the usual type with occasional traces of nummulites, and here and there a few thin bands of soft shale. The southern face of the ridge is composed of massive scarps of the limestone. Near the western extremity Upper Nummulitics come in on the north flank and are especially well seen at Chor Galli, the beds consisting of lumpy limestones, some with purple and dark shaly partings, white splintery shales, greenish shales and hard whitish marly limestone. *Planorbis* has been found in the limestones and all these beds belong to the Lower Chharat or variegated shale zone. About a mile west of Murat bungalow and also at the extreme eastern end of the ridge some of the Upper Nummulitics including the bed of fragmentary lamellibranchs, are recognisable below the basal Murree bed; in the latter spot there is a little associated carbonaceous matter. Elsewhere everything is hidden by scree, but there is not room for more than a trace of the Upper stage. The smaller ridge to the west is made up entirely of Upper Nummulitics, comprising hard, fine, cream-coloured limestone rising like a wall with parallel sides and fantastically carved, a little purple shale and some rather bleached bedded limestone. The exposures in the Sil river, to the east of the main ridge, are composed of 500 feet of purple and olive shales belonging to the Upper stage.

The beds forming the Dhok Maiki ridge, and for at least a mile on either side, are vertical or very steep, and the boundary between the Nummulitics and the beds immediately to the south, whatever they are, is evidently a reversed fault, since the Nummulitics are either in contact with or very close to the Siwaliks, and the Murrees either very thin or completely absent. Judging from the consistent steepness of the beds of the head of the fault must be very small. It is this fault which has been traced westwards to the Indus. The main Khair-i-Murat ridge of Lower Nummulitic limestone is also bounded on the south by a fold fault, though this appears to be off the line of the Dhok Maiki fault. The southern boundary of the Nummulitics cropping out in the Sil river is also probably a reversed fold fault, so that the faulting, like the three outcrops, seems to be echelonned slightly, in each case a little to the south as we pass eastwards. There

is no trace of faulting along the northern side of the ridge, and its structure is that of a contorted and fold-faulted sinuous anticline, overfolded towards the south and pitching normally at either extremity. The general dip is steep and towards the north, but is usually not every steady. Where the anticline swings round minor branch folds are given off, and the limestone in places shows brecciation.[203]

The two upper marine zones of the Chharat stage have not been recognised and the Upper Nummulitic beds of the Khair-i-Murat area belong entirely to the variegated shale zone, which increases in thickness westwards and at the end of the main ridge constitutes the only Eocene exposed. There is thus good evidence of unconformity and overlap in the unfaulted sequence on the north side. The Upper Nummulitic shales are of the usual red, purple or indigo colour, and the limestone bands are full of the *Planorbis* found in the Chharat area.[204]

As already noted, the Chharat succession can be recognised as such to the west of the Indus at Banda Daud Shah, at Bahadur Khel, and at Saidgi, 15 miles west of Bannu.

The Salt Range.—Eocene beds carrying nummulites and other foraminifera have been met with in the borings of the Attock Oil Co. in their oil fields of Khaur and Dhulian to the east and southeast of Pindigheb at depths, in the former of about 5,300 feet and in the latter of about 7,400 feet. The dome structures of these two contiguous oilfields are situated within the zone of more open folding. So far as can be ascertained, the Chharat beds are partially, if not completely below ground. On the surface, however, the Eocene is not again met with south of Khair-i-Murat till the southern margin of the plateau is reached in the Salt Range.

Whatever the age of the basal beds of the Salt Range scarp may be, there is no ambiguity concerning the Palæocene-Eocene age of the beds at the top, which have been ably described by L. M. Davies and E. S. Pinfold.[205] They have been subdivided by Gee into six stages, all of them showing much lateral variations:

Sequence.		Thickness (excluding doubtful or exceptional local developments).
Laki	Bhadrar beds (? Lower Chharat)	100-300 feet
	Sakesar Limestone	200-500 „
	Nammal limestones & shales	100-250 „
	Unconformity	
Upper Ranikot	Patala Shales	100-250 „
	Khairabad Limestone	50-1000[205] „
	Dhak Pass beds	20-150 „

[203] E. H. Pascoe. Mem. 40, 401 (1920).

[204] E. S. Pinfold, Rec. 49, 149 (1918).

[205] Pal. Ind., New Ser., 24, Mem. 1 (1937). Mr. Gee's Memior on the Salt Range is still in preparation, but some notes very kindly supplied by him, as well as Mr. Pinfold's published descriptions, have been used in the construction of this section.

A typical section in the vicinity of Khairabad, not far from the western end of the range, where all stages except the topmost stage are well developed is as follows:

Laki	Lower Chharat	
	Sakesar Limestone	approx. 250 feet
	Nammal limestones and shales . . .	200 ,,
	——— unconformity ———	
Upper Ranikot	Patala shales	...250 ,,
	Khairabad Limestone	150-1250[206] ,,
	Dhak Pass beds	thin and variable

Between Khairabad and Jaba in the northern end of the Tredian hills, the combined thickness of the Palæocene and Eocene is more than 2,000 feet; near Nammal it totals about 1.200 feet in spite of the absence of the topmost stage; in the Nilawan gorge only 550 feet represent this sequence and this is reduced to 400 or 450 feet around Dandot and Choa Saidan Shah; from the Chambal ridge and westwards to the area northeast of Baghanwala the beds are absent altogether but are thin and impersistent in the Jogi Tilla ridge in the extreme east.

One of the chief unconformities in the Salt Range succession, occurs beneath the Palæocene and was first recognised by Wynne. The oldest member of latter series is a thin irregular bed of ferruginous shale, 5-15 feet thick. often pisolitic and evidently representing an old land surface.[207] One of those lateritic beds so characteristic of the Tertiary contact with the beds below, it belongs to no fixed horizon but marks the unconformity from west to east throughout. In the extreme east it rests on the Salt Pseudomorph beds and the Talchir shales, in the centre on the Productus Limestone, while in the western half of the range it overlies various members of the Mesozoic succession. At Choa Saidan Shah Pinfold found no more than 100-200 feet of Speckled Sandstone separating the Ranikot from the upper carboniferous boulder bed. At Kalabagh, on the west side of the Indus, the base of the Palaeocene-Eocene rests upon the Cretaceous Belemnite Shales. In the ravine east of Nurpur, the place of the basal pisolite seems to be taken by a thin bed of deeply iron-stained travertine. This red lateritic shale or clay passes laterally into coarse, felspathic grits and sandstones of no great thickness; the

[206] 1,250 feet have been recorded, but this excessive thickness is probably either a result of repetition by strike faulting or due to the upper portion of the limestone representing a calcareous development of part of the Patala Shales.

[207] The 'Haematite Bed' of Wynne (Mem. 14, 106 (1878).

change indicated by this passage from terrestrial to aqueous conditions is marked in places by the occurrence of carbonaceous strata.

There is also a distinct unconformity, though of much less importance, between the Ranikot and Laki. Followed northwards from the Patala *Nala*, near Nammal, in the western part of the range, the Patala Shales thin out, and disappear, and at Kalabagh on the other side of the Indus, there is but a remnant of the Khairabad Limestone and this is in direct contact with the Nammal stage of the Laki. In the eastern part of the Salt Range there is a similar progressive overstepping by the Laki which eventually comes into contact again with the Khairabad Limestone near Kalar-Kahar and Choa Saidan Shale.

In the west the Patala stream-course shows a good section of the beds, resting upon the plant-bearing Jurassic, the total thickness of the Upper Ranikot here being about 430 feet. Near Kalar-Kahar the total thickness of the Ranikot is less than 100 feet; here the Patala Shales are missing and the Khairabad Limestone is reduced to 30 feet.

The Dhak Pass beds consist of sandstones and shales. Above the basal ferruginous pisolite in the Patala stream-course, this stage is made up of about 40 feet of ochreous, lavender or carbonaceous shales, containing gypsum and abundant vegetable remains. These are followed by 35 feet of massive ferruginous sandstone, occupying a pronounced scarp, and yielding occasional foraminifera of Upper Ranikot type. It is capped by a thin calcareous sandstone, seldom more than a foot in thickness, which is crowded with well preserved gastropods, lamellibranchs, corals, a small *Terebratula* and a few foraminifera. This fossil band, at the top of the Dhak Pass stage, is described as forming an easily recognisable horizon over the greater part of the Salt Range. Lithologically the lower portions of the stage have more in common with the Lower Ranikot (Hangu Shale), though there is no palaeontological evidence to show that anything older than Upper Ranikot is present in the Dhak Pass beds. The following fossils nearly all of them from the topmost calcareous band, have been identified, the foraminifera and the arthropod by Col. Davies, the brachiopod by Miss Muir-Wood, the mollusca by L. R. Cox and the ostracods by Miss Latham.[208]

FORAMINIFERA.

Operculina cf. *canalifera* d'Arch.,
Operculina subsalsa Dav.,
Miscellanea miscella (d'Arch. & H),
Lockhartia haimei (Dav.).
Lockhartia conditi (Nutt.).
Lepidocyclina (Polylepidina) punjabensis Dav.[209]

[208] Pal. Ind., New Ser., Vol. 24, No. 5 (1937); Proc. Roy. Soc. Edin., 59, pt. 1, No. 4, 45 (1938); Probably also from this horizon comes *Lamna* sp., Rec. 72, 174 (1937).

[209] A very early occurrence of the genus which in India is mostly confined to the Oligocene and Miocene, and in America is not found before the Middle Eocene.

BRACHIOPODA

"*Terebratula*" *flemingi* Davidson (not a true *Terebratula*).

LAMELLIBRANCHIATA.

Ostraea (Flemingostraea) pharaonum Oppenh., var. *aviculina* Mayer-Eymar,
Crassatella salsensis (d'Arch. & H.),
Crassatella (Pseuderiphyla) cf. *blanfordi* Cossm. & P.,
Lucina noorpoorensis d'Arch. & H.,
Lucina (Pseudomiltha) vredenburgi Cossm & P.,
Diplodonta cf. *hindu* Cox.

GASTROPODA.

Liotia (Liotina) imperforata Cossm. & P.,
Terebellum distortum d'Arch. & H.,
Cassidaria cf. *archiaci* Cossm. & P.,
Megalocypraea ranikotensis Schild.,
Athleta (Neoathleta) cf. *sihesurensis* (d'Arch. & H.),
Velates perversus (Gmel.),
Velates perversus var., *noetlingi* (Cossm. & P.),
Ampullina (Crommium) dolium (d'Arch. & H.),
Ampullina rouaulti (d'Arch. & H.),
Ampullospira (Euspirocrommium) oweni (d'Arch. & H.),
Ampullina (Pachycrommium) flemingi (d'Arch. & H.).

ARTHROPODA.

Bairdia subdeltoidea (Münst) (found at all levels from Dhak Pass to the Bhadrar beds; found in Kohat throughout the entire Eocene from the Lower Ranikot to the uppermost Kirthar).
Cythereis mersondaviesi Lach.

In the Nammal gorge and the Dhak Pass the Dhak stage is somewhat thicker than it is in the Patala stream-course and the sandstone is divided into two or more beds by intercalations of ferruginous shale; in the more easterly sections the Dhak stage is absent.

The Khairabad Limestone, a well marked calcareous formation and perhaps the equivalent of the Lockhart Limestone of Kohat, is for the most part a nodular, foraminiferal limestone, but it is characterised by the occurrence in its lower and uppermost portions of thin impersistent shales. In the eastern part of the Salt Range it is represented by only a few feet of grey shales with thin limestones; these thicken westwards to about 200 feet in the Nammal section and near Khairabad, in the western end of the Range, the stage is almost wholly calcareous and reaches an unusual thickness at least 1,000 feet. Lithologically the limestone differs from the Sakesar Limestone in its more consistently nodular character, in the presence of marcasite and in the absence of chert; the decomposition of the iron content is responsible for the usual yellow or brown colour on weathered surfaces. Like those of the limestone, the calcareous nodules in the shales are made up almost entirely of foraminiferal tests; from the upper portions of this stage has been collected the richest foraminiferal fauna found in the Salt Range Eocene. The lower, shaly portion, which is somewhat variable in character, has yielded the following casts of lamellibranchs,[210] and two ostracods.[211]

[210] Dr. L. R. Cox, Pal. Ind., New Ser. 24, No. 1, 7 (1937).
[211] Miss Latham. Proc. Roy. Soc. Edin., 59, pt. 1, No. 4, 45 (1938).

GASTROPODA.

Velates noetlingi Cossm. & P ,

LAMELLIBRANCHIATA.

Lucina vredenburgi Cossm. & P.,
Lucina cf. *bellardi* d'Arch. & H.,
Megalocypraea ranikotensis Schild.

OSTRACODA.

Bairdia subdeltoidea (Münst.),
Cythereis mersondaviesi Lath.

Both the nodules and the interstitial shaly matter of the nodular limestone, are richly fossiliferous and crowded with foraminifera identical with most of the Ranikot species; in addition are several echinoderms and casts of lamellibranchs and gastropods, the latter showing a close resemblance to those found in the Nammal stage above the unconformity. The higher levels of this stage have yielded the following Foraminifera, echinoderms (Col. L. M. Davies), mollusca (Dr. L. R. Cox), and ostracods (Miss Latham):

FORAMINIFERA.

Bigenerina sp.,
Verneuilina sp.,
Nummulites nuttali Dav.,
Nummulites sindensis (Dav.),
Nummulites globulus Leym.,
Nummulites cf. *mamilla* Ficht. & Moll.,
Assilina dandotica Dav..
Assilina subspinosa Dav.,
Operculina cf. *canalifera* d'Arch.,
Operculina subsala Dav.,
Operculina patalensis Dav.,
Operculina jiwani Dav. (allied to *O. patalensis*),
Miscellanea miscella (d'Arch. & H.),
Miscellanea stampi (Dav.),
Dictyoconoides flemingi Dav.,
Alveolina vredenburgi Dav.,
Alveolina ovoidea d'Orb. (=*A. subpyrenaica*, *A. decipiens* of the Libyan beds, and Carter' *A. sphaeroidea*),
Alveolina globosa Leym. (=d'Orbigny's *A. melo*, and *A. pasticillata* of the Libyan beds).

ECHINOIDEA.

Eurhodia morrisi (d'Arch.) var. *salsensis* Dav.,
Plesiolampas placenta Dunc. & Sl.,
Plesiolampas ovalis Dunc. & Sl.,
Hemiaster elongatus Dunc. & Sl.,
Conoclypeus warthi Dav.[212]

LAMELLIBRANCHIATA.

Lucina (Pseudomiltha) mutabilis Lam.,
Lucina noorpoorensis d'Arch. & H.,
Spondylus cf. *raduia* Lam.,
Ostraea (Flemingostraea) pharaonum Oppenh., var., *aviculina* Mayer-Eymar,

[212] Rec. 59, 366 (1926).

GASTROPODA.

Velates perversus (Gmel.),
Cerithium (*Campanile*) cf. *brookmani* Cox.,
Bairdea subdeltoidea (Münst.),
Cythereis bowerbanki Jones.,
Cythereis mersondaviesi Lath. ..

This fauna is typical Upper Ranikot and unmistakable, having most in common with Dr. Nuttall's higher subdivision, B, the equivalent of Vredenburg's highest zone (No. 4) of the Sind succession. Fossil algae have been recognised by Messrs. L. R. Rao and K. S. Rao in the Khairabad Limestone, [213] and from this limestone probably comes the tooth of an unknown species of shark belonging to the genus Lamna.[214]

The succeeding stage has been named by Pinfold and Davies the Patala Shales after the stream-course in which it attains a maximum development, and is composed mainly of dark grey shales. The shales are sometimes carbonaceous but not to the extent shown by the shales of the Dhak stage. According to Gee. the impersistent coal seam of the Dandot coalfield belongs to this horizon.[215] The Dandot coal, a friable lignite with a large percentage of sulphur in the form of iron pyrites, occurs as a small basin-shaped seam, from 1½ to a little over 3 feet thick, in the Pind-Dadan-Khan subdivision of the Jhelum district.[216] Nineteen miles further east is the Baghanwala seam of similar character, rising in places to 7 feet in thickness, but passing horizontally into carbonaceous shales and sandstones; specks and nests of fossil resin are a feature of this coal.[217] In the middle portion of the Salt Range this stage includes a basal zone of massive and often carbonaceous sandstone, 100 feet thick, which Mr. P. Evans has called the Dilliwali sandstone. In the eastern part of the range this sandstone is not more than 8 feet thick and is intimately associated with the Dandot coal seam, the two appearing to replace one another. Northwest the sandstone dies out beyond Sakesar. From 250 feet in the Nammal or Patala sections the thickness of the whole Patala stage dwindles to some 50 feet in the east.

The most characteristic features of the Patala stage are the occurrence therein of several distinct fossil beds, separated by unfossilliferous shales, and the abundant individuals but few species found in each fossil bed. The following measured section in the Patala *nala* is recorded by Pinfold and Davies:

l. Impersistent ferruginous grit	1 foot
k. Calcareous marl, corwded with foraminifera . . .	4 feet
j. Dark grey shales	30 „

[213] "Current Science", 8, 512 (1939).

[214] S. L. Hora, Rec. 72, 174 (1938).

[215] Gen. Rep. Rec. 69, 71 (1935); Pinfold refers the Dandot coal to the Dhak stage.

[216] R. R. Simpson, Mem. 41, 110 (1913); see also E. R. Gee Trans. Min. Geol. Met. Inst. Ind., 33, 278 (1938).

[217] Mem. 41, 109 (1913); T. H. D. La Touche, Rec. 27, 18 (1894).

i. Calcareous band, with foraminifera and other fossils .	2 feet
h. Dark grey shales	70 "
g. Brown, ferruginous limestones with foraminifera, *Ostraea*, etc.	15 "
f. Dark grey shales, with the teeth of a pycnodont fish and of a form resembling the late Cretaceous species, *Lamina appendiculata*	20 "
e. Shales with calcareous nodules	60 "
d. Marl, full of well preserved Operculina Salsa and *Lepidocyclina* (*Polylepidina*) *punjabensis*, with many other small foraminifera and numerous entomostraca . .	1 foot
c. Nodular limestone and shales	15 feet
b. Fibrous gypsum	½ foot
a. White limestone	7 feet
(Dilliwali sandstones absent)	—
	225½ "

This section has been given in detail because its topmost beds (the Pail Limestone of Evans) and perhaps also its middle, represent higher Ranikot horizons than any found in Sind or Baluchistan.[218] At about the middle of the stage, just below the ferruginous limestones of bed "g", there is a marked change in the foraminiferal fauna, earlier types such as *Miscellanea miscella, Lockhartia haimei* and *Lepidocyclina punjabensis* becoming either extremely scarce or extinct, while later ones like *Operculina patalensis, Assilina dandotica* and *Discocyclina ranikotensis* increase in numbers and ultimately dominate the assemblage; *Nummulites nuttalli* is one of the species which has not yet been found above this level.

The limestones of bed "g" are rendered conspicuous by their ferruginous character. The lower part of this bed ("g") is crowded with *Operculina patalensis* and *Lockhartia newboldi*, while *Discocyclina ranikotensis* and a globose *Ostraea* are abundant near the top; other forms like *Assilina dandotica* are numerous throughout. From this bed also come the echinoid, *Dictyopleurus ziczac* Dunc. & Sl., and the coral, *Trochocyathus* cf. *epithecata* (Dunc). From about this horizon come *Nummulites globulus* Leym. and *Astrocoenia blanfordi* Dunc. The arthropod, *Bairdia subdeltoidea* (Münst.) is found throughout the Patala Shales.

The fauna of bed "i" belongs to the later type and includes:

FORAMINIFERA.

Assilina dandotica Dav.,
Operculina patalensis Dav.,
Lockhartia newboldi (d'Arch. & H.),
Discocyclina ranikotensis Dav.

LAMELLIBRANCHIATA.

Ostraea (*Flemingostraea*) *pharaonum* Oppenh., var. *aviculina* Mayer-Eymar,
Crassatellites salsensis d'Arch. & H.,
Cardita (*Venericardia*) *semi-inflata* Cossm. & P.,
Teredo intestinoides Cossm. & P.,
Corbula cf. *harpa* d'Arch. & H.

[218] Only the lowest horizons of this stage can be matched with the highest zone in Sind.

GASTROPODA.

Velates perversus (Gmel.),
Mesalia fasciata (Lam.),
Turritella ranikoti Vred.,
Turritella halaensis Cossm. & P., ("*Turritella hollandi*" Vred.),
Turritella cf. *diastropha* Cossm. & P.,
Cerithium cf. *angyostoma* (d'Arch. & H.),
Eutritonium (*Sassia*) cf. *permutabile* Cossm. & P.

Whether bed "k", the highest fossiliferous bed, can be matched in the highest of the Samana horizons is not quite certain. but its occurrence in the Patala stream-course is of special interest since this locality is the only one east of the Indus in which such a high Ranikot horizon has been observed. The following foraminifera have been identified by Col. Davies:

Nummulites globulus Leym.,
Nummulites lahirii Dav.,
Assilina dandotica Dav.,
Operculina cf. *canalifera* d'Arch.,
Operculina salsa Dav.,
Operculina patalensis Dav.,
Discocyclina ranikotensis Dav.

Nummulites lahirii externally resembles the Laki form *Nummulite atacicus,* but the general aspect of the fauna is distinctly Ranikot From an isolated section, south of Dandot and underlying the Laki limestones, some highly fossiliferous Ranikot clays of different character from those of adjacent outcrops in the main range, have yielded a fauna peculiarly rich in ostracods and belonging apparently to the lower portion of the Patala Shales; these include: *Bairdia subdeltoidea* (Münst.), *Cythereis mersondaviesi* Lath., *C. bowerbanki* Jones, *C.* cf. *spiniferrima* Jones & Sherb., *Cytheridia perforata* var. *insignis* Jones, *Cythere ranikotiana* Lath., *C. costellata* (Roem.) and *Bairdia* cf. *contracta* Jones.[219] Amongst the foraminifera Col. Davies has identified:

Nummulites thalicus Dav. (probably the megalospheric form of *N. sindensis*),
Assilina dandotica Dav.,
Operculina salsa Dav. (recalling *O. ammonea* Leym.),
Operculina subsalsa Dav.,
Miscellanea miscella (d'Arch. & H.),
Lockhartia haimei (Dav.),
Lockhartia newboldi (d'Arch. & H.),
Lockhartia conditi (Nutt.),
Lepidocyclina (*Polylepidina*) *punjabensis* Dav.

A complete list of the foraminifera from the Patala Shales is as follows:

Nummulites nuttalli Dav.,
Nummulites thalicus Dav..
Nummulites sindensis (Dav.),
Nummulites globulus Leym.,
Nummulites cf. *mamilla* (Ficht. & Moll),
Assilina dandotica Dav.,

[219] Mary H. Latham. Proc. Roy. Soc. Edin. 59, pt. 1, No. 4, 45 (1938).

Assilina subspinosa Dav.,
Operculina subsalsa Dav.,
Operculina cf. *canalifera* (d'Arch),
Operculina salsa Dav.,
Operculina patalensis Dav.,
Operculina jiwani Dav.,
Miscellanea stampi (Dav.),
Miscellanea miscella (d'Arch. & H.),
Lockhartia haimei (Dav.),
Lockhartia newboldi (d'Arch. & H.),
Lockhartia conditi (Nutt.),
Lockhartia tipperi (Dav.),
Lepidocyclina (Polylepidina) punjabensis Dav.,
Discocyclina ranikotensis Dav.,
Alveolina vredenburgi Dav.,
Alveolina ovoidea d'Orb.,
Alveolina globosa Leym.

Above the unconformity is the Nammal stage, consisting of white limestones, marls and grey or greenish shales in varying proportions. In the Patala stream-course are exposed 400 feet of these beds, in the upper levels of which are found the earliest occurrences of the typical Laki species, *Assilina granulosa* and *Nummulites atacicus* associated somewhat abnormally with fossils of Ranikot affinities. From the Nammal gorge northwards as far as Kalabagh this stage is more consistently Laki in the composition of its fauna; the larger foraminifera are confined to a thin bed made up almost entirely of the test of *Nummulites irregularies* Desh., and its megalospheric form *N. subirregularies* de la Harpe, *N. atacicus* Leym., and *Assilina granulosa* (d'Arch.), (some of them of exceptionally large diameter), together with the long-ranging species common to both Ranikot and Laki, *Nummulites lahirii* Dav., *Lockhartia tipperi* (Dav.) and *Discocyclina ranikotensis* Dav., in the adjacent marls alveolines are frequently abundant. This fossil bed attains its maximum development to the northwest of Jaba, where it is crowded with fossils. The basal beds of the Laki in the eastern parts of the Salt Range are characterised by numerous molluscan remains, chiefly gastropods and the casts of large lamellibranchs belonging to such genera as *Velates* and *Lucina*. Near Choa Saidan Shah the base of the Laki is an oyster bed made up of the tests of *Ostraea flemingi*. The relative proportion of shale and limestone varies, and the upper boundary of the stage is not always definite, especially in eastern sections where this and other members of the Eocene are considerably reduced in thickness; at Choa Saidan Shah the latter appears to be less than 90 feet, and in sections east of Kalarkahar the stage seems to be absent altogether, typical Sakesar Limestone lying in contact with the Khairabad Limestone. The Nammal limestones are described as chertless. This stage is usually covered by scree from the overlying Sakesar Limestone cliffs.

Dr. Cox's list of Laki mollusca from the Salt Range, belonging probably largely to the Nammal stage but possibly including forms from the Sakesar limestone, is as follows:[220]

GASTROPODA.

Blagraveia sindensis (d'Arch. & H.),
Volutospina sihesurensis (d'Arch. & H.),
"*Cerethium*" *flemingi* (d'Arch. & H.),
Ampullospira,
Euspirocrommium oweni (d'Arch. & H.),
Euspirocrommium cossmanni (Vred.),
Keliostoma subturricula Cox, (close to the Paris form, *K. turricula* Burg.),
Hippochrenes cf. *amplus* (Sol.),
Rimella jamesoni (d'Arch. & H.),
Rimella cf. *prestwichi* (d'Arch & H.) (Middle Laki of the Nilawan ravine ; a Ranikot form), ...
Terebellum carcassense Leym.,
Terebellum cf. *distortum* d'Arch. & H. (Ranikot form ; also in the Danian of Tibet and the Middle Eocene of Asia Minor).
Gisortia (Vicetia) metingensis (Vred.) (? Laki),
Volutospina sihesurensis (d'Arch. & H.),
Volutospina teelaensis (d'Arch. & H.),
Gosavia humberti (d'Arch & H.), (Middle Laki of the Nilawan ravine),
Rostellaria (Tibia ?)noorpoorensis (d'Arch & H.) (from Nurpur, Punjab Salt Range).

LAMELLIBRANCHIATA.

Ostraea (Liostraea) flemingi d'Arch. & H.,
Spondylus rouaulti d'Arch. & H. (? Laki),
Cardita dufrenoyi d'Arch. & H. (Ghazij Shales ; Middle to Upper Laki),
Cardita viuesneli d'Arch. & H.,
Crassatella salsensis d'Arch. & H.,
Lycina (Pseudomilthia) noorpoorensis d'Arch. & H. (between Warchs and Sakesar ; also Upper Laki (?) ; Nummulitic limestone with flints at Nurpur ; Europe ; N. Africa ; S. Arabia ; Iraq ; Persia),
Lycina (Eomiltha) punjabensis d'Arch. & H.,
Blagraveia sindensis (d'Arch. & H.) Ghazij Shales ; (Middle to Upper Laki),
Cardium salteri (d'Arch. & H.) (? Laki),

Of similar though more constant lithological character, but having a distinct foraminiferal fauna, is the Sakesar Limestone which follows. To this stage belong the massive limestones which form the southern edge of the Potwar plateau and are exposed in the precipitous cliffs of the main scarp of the Salt Range. They are of light grey colour, sometimes massive, sometimes nodular with a considerable development of chert in their upper layers. Maris are relatively subordinate From Ara westwards this stage thickens rapidly and is about 180-200 feet thick as far as Katha. In the Patala stream-course the total thickness of the stage is 240 feet, but beyond Nammal it reaches a figure of 500 feet or more. To the north and south of the Jaba *Nala* near Daud Khel, this limestone passes into massive white gypsum about 300 feet thick. In the hills south of Mari, a small town on the Indus nearly opposite to Kalabagh, the Sakesar stage is present in the form of massive white cherty limestone with an abundant Laki fauna, but in the neighbourhood of Khairabad it is locally

[220] Trans. Roy. Soc. Edin., Vol. 57, 25 (1934).

missing; in this much faulted region structural causes may have played a considerable part in its disappearance but Pinfold suggests that the latter is probably due partly to thinning out of the beds and partly to the erosion which produced the unconformity between the Sakesar and the overlying Chharat. North of Kalabagh, on the other side of the Indus, the Sakesar Limestone is well developed and forms precipitous scarps of white or light grey massive limestone, crowded with *Alveolina*. It is probably the Sakesar Limestone which forms the principal constituent of the Hill limestones of the Potwar and Kala Chitta.

As in the underlying stage, the distribution of fossils is capricious; near Nammal they are restricted to the higher horizons but further north and east they are more evenly scattered throughout the stage. The Sakesar Limestone appears to be the equivalent of the Meting Limestone of Sind, or the Dunghan Limestone of Baluchistan. Foraminifera are abundant; the following have been identified by Col. Davies:

Nummulites atacicus Leym.,
Nummulites cf. *mamilla* Ficht. & Moll.,
Assilina granulosa (d'Arch.),
Assilina spinosa Dav.,
Lockhartia tipperi (Dav.),
Lockhartia newboldi (d'Arch. & H.),
Sakesaria cotteri Dav. (a new genus, allied to *Lockhartia*; the species only found in the lower parts of the Sakesar Limestone and the upper levels of the Nammal Shales),
Heterostegina cf. *ruida* Schwag. (found in the Libyan beds of Egypt).
Alveolina ovoidea d'Orb.,
Alveolina globosa Leym.,
Alveolina oblonga d'Orb.

ECHINOIDEA (COL. DAVIES).

Conoclypeus warthi Dav.,
Echinolampas nummuliticus Dunc. & Slad.

The mollusca recognised by Dr. L. R. Cox comprise:

LAMELLIBRANCHIATA.

Lucina noorpoorensis d'Arch. & H.,
Ostraea (*Liostraea*) cf. *rouaulti* (Mall. ?) Cox.,
Ostraea flemingi d'Arch. & H.,
Cardita (*Venericardia*) cf. *subcomplanata* (d'Arch. & H.),
Spondylus cf. *radula* Lam.

GASTROPODA.

Velates perversus (Gmel.),
Gisortia (*Vicetia*) *metingensis* Vred.

The ubiquitous *Bairdia subdeltoidea* (Münst.) is reported from this stage. *Lockhartia tipperi* and the alveolines are abundant in the limestone near Choa Saiden Shah, where they are occasionally beautifully preserved in chert. Flosculinised alveolines are characteristic of the stage and occur, somewhat sporadically, throughout. In the Patala stream-course and the Nammal and Dhak Pass sections, con-

siderable portions of the limestone are barren of organic remains visible to the naked eye; in the Majuchh *Nala* it is described as crowded with *Alveolina*.

On the plateau and dip slopes in the certral parts of the range, as for example at Kalar-Kahar and Choa Saidan Saha, occurs a higher Upper Laki stage to which Mr. Gee has given the name of Bhadrar. It has been divided into three zones. The lower, consisting of some 75 feet of fossiliferous shales and marls with a few thin limestone bands.

(c) Upper.—Red and green, gypseous clays and shales, occurring mainly in the vicinity of Jaba in the northern end of the Tredian hills where they attain a thickness of about 300 feet; elsewhere, they are probably represented by a thin sequence of purple calcareous clays at Kalar Kahar in the eastern part of the range.

(b) Middle.—Thin, hard, light-coloured limestones with marls, attaining a maximum of about 80 feet near Kala Kahar; in the west, around Jaba, these beds are only 30 feet thick, consisting of limestones and marls with a thin basal conglomerate which, in the absence of the Lower zone, rests directly on the Sakesar stage.

(a) Lower.—Fossiliferous shales and marls with a few thin bands of limestone, totalling some 75 feet on the Dialwal plateau between Choa Saidan Shah and Kalar Kahar but dying out eastwards, and also eastwards near Pail.

There is thus a distinct unconformity between the Sakesar Limestone and the Bhadrar stage. The Middle zone of the latter closely resembles the Chorgalli Limestones or Passage Beds of the Potwar and Attock areas, and both Pinfold and Evans suggest a correlation. The Upper zone, furthermore, is strongly reminiscent of the Variegated Shales of the Lower Chharat sequence.

The marls of the Bhadrar stage contain abundant *Orbitolites complanatus*, a form found nowhere else in the Salt Range, and *Assilina daviesi*, a combination recalling the Shekhan Limestone of Kohat; the fauna in general, however, is different from and probably somewhat older than that of the Shekhan stage. *Alveolina ovoidea* d'Orb. has also been found in the Bhadrar beds, as well as the ostracods, *Bairdia subdeltoidea* (Münst.) and *Cythereis bowerbanki* Jones. These softer beds probably extend at least as far west as Chamil and are believed to be present in the Patala stream-course; at Jaba the limestone is missing and the marls are in direct contact with the overlying Siwalik beds (Kamlial).

Along the northern flank of the Salt Range, Lower Chharat beds have been noted by Pinfold at several localities between either the Bhadrar stage or the Sakesar Limestone and the sandstones of the Upper Tertiary (basal Kamlials). The most frequently seen deposits consist of splintery, well-bedded, porcellanous white limestones, associated sometimes with grey or ochreous, gypseous shales. In the Patala and Nammal sections these beds are either absent or poorly represented. In the Sokan syncline and on the west flank of the Jaba

anticline these white limestones are associated with about 50 feet of overlying bright scarlet clays which, further northwest, become more conspicuous and form a continuous belt along the eastern flank of the Jaba anticline. The scarlet clays and underlying massive gypsum at Ainwan, a short distance southeast of Mari, were assigned by Wynne to the Salt Marl but are believed by Pinfold to belong to the Chharat. The limestones of these beds as Pinfold remarks, are frequently barren of organic remains but in some of them small spherical bodies believed to be spores have been noted. These rocks are described as exactly similar to the limestones at the base of the Lower Chharat stage near Chharat and elsewhere; the scarlet clays, although apparently devoid of *Planorbis*, are evidently the equivalent of the Planorbis Shales or of the "Red Clay" of the Kohat salt region. Near Mari, the base of the Lower Chharat, represented by massive gypsum, is in contact with the Nammal Limestones and shales, the Sakesar Limestone being locally absent.

From a study of the foraminifera, Col. L. M. Davies is inclined to equate the Sakesar Limestone with the Dunghan and Meting Limestones of Baluchistan and Sind, which belong to the Lower Laki; this would make the Nammal stage very early Laki. Col. Davies prefers to correlate the Bhadrar Beds with the Meting Shales or Middle Laki, and to regard the Upper Laki—equivalent to the Shekhan Limestone of Kohat or the Laki Limestone of Sind as non-existent in the Salt Range. [221] This observer remarks on the fact that while the Ranikot stages are comparatively constant in palaeontological character throughout the Salt Range and show recognisable vertical transitions from one to the other, the Laki stages at various points of the Range show no such constancy of faunal character and are frequently not easy to distinguish. This may be due partly to lateral change in facies, but may also be largely the result of the local incompleteness of the fossil collections so far obtained and examined.

The Trans-Indus continuation of the Salt Range.—The detailed examination made in the case of much of the Salt Range Eocene has not yet been extended to the same series of rocks in the trans-Indus continuation of the range, known as the Maidan or Chichali range. except at Kalabagh to which references have already been made. The structure here is that of a fold-faulted anticline stretching from the neighbourhood of Kalabagh due north up the Luni Wahan. The section near Kalabagh shows some marked differences from that at Mari across the Indus and three or four miles to the southeast. The basal portion of the Kalabagh hills is occupied by salt beds which are believed to be of the same age as those of Mari and are assigned by Gee to the Saline series. According to Wynne,[222] the Kalabagh salt beds are greatly disturbed and contorted, a condition which Middlemiss attributes to movement of the overlying strata; [223] they include

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[221] Private Communication.

[222] Mem. 17, 247 (1880).

[223] Rec. 50, 77 (1919).

besides salt-marl, gypsum and rock-salt, bands of dolomite and dark coloured shale, and are overlain mostly by the Productus Limestone or the Jurassic, the Purple Sandstone being absent. In other parts of the Kalabagh hills, however, Upper Tertiary (Siwalik) strata are seen overlying the same saline sequence, which is composed of gypsum, dolomite and shales, underlain by thick deposits of salt-bearing marl; these deposits continue southeastwards across the Indus in the salt hill of Mari. The nearest unquestionable exposure of the Kohat rock-salt and gypsum deposits of undoubtedly Tertiary age is at Shakardara, 17 miles due north of Kalabagh, where the beds are seen to pitch southwards and eastwards below the Lower Chharats. There are, however, some intermediate occurrences of saline beds whose age is a matter on which opinions differ. Between Kalabagh and Shakardara the general strike is N.-S. along a syncline and anticline involving Siwalik beds. About half-way along the anticline, *i.e.*, about 8 and 10 miles up the Luni valley, are two small faulted inliers of rock-salt overlain by gypsum and dolomite, lying in the Siwalik strata. These are regarded by Gee as belonging to the Saline series (? Pre-Cambrian or Cambrian), to which they were doubtfully referred also by Wynne; by others they have been equated with the Tertiary salt and gypsum of Kohat. In no other part of the Maidan range are these salt and gypsum beds found, nor do they occur in its continuation across the Kurram river, the Marwat (Mohrut) range.

From a point five or six miles north of Kalabagh, rocks of undoubted Palaeocene and Eocene age have been traced westwards and southwards in the curving Maidan range, increasing at the same time in thickness. Near the Chichali Pass the total thickness of the Palæocene-Eocene succession is 950-1,000 feet, the highest stage being the Sakesar Limestone. Halfway along the range, according to Wynne, they are estimated to be 1,500 feet, while at Makarwal, further along, the beds attain a maximum of 1,850 feet and pitch southwards beneath the overlying Siwaliks. South of the Kurram river they are absent.

The Ranikot of Kalabagh includes a well developed basal ferruginous pisolite, which overlies, with an unconformity which is not visible in single sections, greensands and belemnite shales of Mesozoic age. Above the pisolite come 100-200 feet of dark grey alum shales with calcareous bands at their base, and these are overlain by 50-76 feet of nodular limestone. The alum shales, which for many years have been worked for alum, are described by Pinfold as full of Patala Shale fossils, while the thin limestone bands found occasionally at or near their base are said to contain a fauna resembling that of the Khairabad Limestone;[224] the latter stage, therefore is evidently here greatly reduced, while the Dhak sandstones and shales appear to be absent altogether unless some of the lowest shales belong to this stage. The nodular limestone above the alum shales might at first sight be mistaken for the Khairabad Limestone, but the foraminifera

[224] Pal. Ind., New Ser. Vol. 24, No. 1, 9 (1936).

recognised therein by Col. Davies have Laki affinities and the bed has been correlated with the top of the Ranikot (Bed "k"); the foraminifera are:

Nummulites globulus Leym.,
Nummulites cf. *mamilla* Ficht. & Mill.,
Nummulites cf. *sindensis* (Dav.),
Nummulites lahirii Dav.,
Operculina salsa Dav.,
Operculina cf. *canalifera* d'Arch.,
Operculina patalensis Dav.,
Assilina dandotica Dav.,
Assilina subspinosa Dav.,
Miscellanea miscella (d'Arch. & H.),
Alveolina ovoidea d'Orb.,
Alveolina (Flosculina) globosa Leym.

Many of the foraminifera found in the Ranikot of the Cis-Indus range occur also in the Kalabagh area.[225] The Patala Shales of Kalabagh have yielded a crab which T. H. Withers finds to be almost identical with *Plagiolophus wetherelli* Bell from the Ypresian beds of Sheppey in England.

Further along the range the basal lateritic bed is seen to be of purely local occurrence, the Palaeocene terminating downwards in a bed of massive sandstone with subordinate carbonaceous shales, at the base of which occur either several feet of the coaly, alum-bearing shales as can be seen in the Chichali Pass, or a workable coal seam, as is the case at Makarwal; this sequence represents the Dhak Pass stage. In the Chichali Pass the junction of these basal Palæocene deposits with the beds below, which are yellowish grey sandstones presumably of Cretaceous age, is a visibly irregular one. The carbonaceous nature of the base of the Palæocene is an indication of terrestrial conditions at that time. The Makarwal coal seam, of lignitic or sub-bituminous character, is usually under 7 feet thick but swells in places to 12 feet; it extends for some 6½ miles.[226] The total thickness of the Dhak beds at Makarwal is 130 feet. The Khairabad Limestone stage at Chichali is represented by 150-200 feet of limestone and marls, while at Makarwal the equivalent strata, mostly a nodular limestone, measure about 160 feet. Similarly the Patala Shale stage at Chichali is made up of some 170 feet of shaly beds; at Makarwal it comprises probably at least 300 feet of olive shales lithologically similar to the alum shales at Kalabagh, with thin limestones and carrying fossils of the Patala stage. The Nammal stage also has been recognised by Gee in the Maidan range and includes at its base a bed containing numerous oysters. To this stage probably

[225] In addition to those already enumerated, the following foraminifera have been recognised from the Kalabagh area. *Nummulites nutalli* Dav., *N. thalicus* Dav., *Operculina jiwani* Dav. (a form probably found in Sind) *Lockhartia haimei* (Dav.), *L. newboldi* (d'Arch. & H), *L. tipperi* (Dav.), *Lepidocyclina (polylepidina), punjabensis* Dav., *Discocyclina ranikotensis* Dav.

[226] V. Ball & R. R. Simpson, Mem. 41, 111 (1913) see also E. R. Gee, Trans. Min. Geol. Met. Inst. Ind., 33, 279-295 (1938).

belong some beds noticed by Wynne, underlying the main limestone, *i.e.* the Sakesar Limestone, and consisting of sandy or marly beds some of them with numerous specimens of *Conoclypeus;* one of the sandstones is of a light yellow colour. Wynne describes the principal rock of the trans-Indus Salt Range as a white, compact or nodular nummulitic limestone of Salt Range character, often filled with casts of fossils. This is no doubt the equivalent of the Sakesar Limestone which Gee identifies as forming a very regular outcrop, 500-600 feet thick near Chichali and probably nearer 900 feet at Makarwal. It is this limestone which is responsible for the extraordinary narrow defile known as the Chichali Pass or *Darwaza,* which pierces the Maidan range nine or ten miles west of Kalabagh; in one place this passage is less than 15 feet wide, the vertical walls on each side towering to heights of 250 or 300 feet. In some places the top of the series is described as consisting of orange or greenish calcareous and concretionary sandstones some of them nummulite-bearing, with grey shales, and a basal band of conglomerate. Whether these are Lower Chharat beds it would be premature to say, but *Chlamys wynnei* is recorded from the Chichali Pass.[227]

In the Marwat and Khasor hills on the other side of the Kurram river no fossiliferous Eocene is seen, the Cretaceous and Jurassic being succeeded immediately by Upper Tertiary beds. At the northern end of the Khasor range, however, some 9 miles south of Isa Khel, there is a large oil seepage, the oil exuding between rocks believed to be of Mesozoic age and a Siwalik conglomerate; six or seven smaller seepages have been noted from the same stratigraphical horizon in the immediate neighbourhood at this end of the range.[228] Since "live" oil indications in northwest India appear to be confined to the Eocene, it is surmised that beds of this series are present below the surface but are concealed by an overlap of the Upper Tertiary rocks.

THE EOCENE OF KASHMIR AND HUNDES.

The Eocene is considerably exposed around Muzaffarabad, where the following stratigraphical sequence is given by Wadia:[229]

Murree Series		
	thrust-plane	
Upper Nummulitic.	Nummulite Shale, and variegated shales with marls and nodular limestones.	500 feet.
Lower Nummulitic.	Black, bituminous, fossiliferous, nodular limestone with few shale partings; grey, flaggy limestone with shales; some silicified beds.	500 feet.

[227] L. R. Cox, Trans. Roy. Soc. Edin., 57, 66 (1934).

[228] F. Parsons. Journ. Inst. Petrol. Techn. Vol. 12, 478 (1926); E. H. Pascoe. Mem. 40, 428 (1920).

[229] Rec. 65, 213 (1931).

Coaly shales, pyritous, gypseous, haematitic; with lenticular quartzitic bands.	0-50feet.

Grey limestone (? Cretaceous).

The Eocene of this area is everywhere cut off from the Murree series by a sharply defined thrust-fault. The most constant member is the Lower Nummulitic limestone which has yielded *Assilina, Nummulites, Dictyoconoides, Operculina,* echinoids and molluscs.

In the sharp syntactical angle several miles further north, the Eocene forms part of the constricted belt of sedimentary formations intervening between the Murrees of the foreland and the crystalline schists of the mountain borders. It occurs in the form of a recumbent anticline with an axial core of Panjal volcanics, in almost unbroken continuity from one side of the re-entrant to the other. The northern limb of this fold is for the most part concealed beneath over-riding sheets of Purana slates and schists thrust from the north, and only a few shreds of the Nummulitic and Trias belonging to this limb are seen. The Eocene of this area is said to bridge to some extent the somewhat divergent facies of this series found in the Pir Panjal and the Potwar Plateau.[230]

Southeast of the Kishenganga the Eocene belt disappears beneath the overthrust but reappears after a gap of several miles and near Uri occurs in a more or less complete recumbent anticline. Along the southwest flank of the Pir Panjal, and with a breadth of outcrop ranging up to three miles, the Eocene occupies an imposing line of precipitous ranges and spurs, rising abruptly from the lower hill masses of Murree rocks to elevations of 8,000-11,000 feet. Further southeast the belt again becomes interrupted, but with wide gaps extends to beyond the Ravi. Along the flank of the Pir Panjal, of which it constitutes the most important morphological unit next to the Panjal volcanics, this belt of Eocene has been thrown into a series of inverted, isoclinal folds, and over the Murree boundary. Wadia gives the following order of superposition: [231]

Murree series.

——thrust-plane——

6. Brightly coloured, variegated, red, purple and green shales, with bands of hard sandstone: unfossiliferous.	900 feet.
5. Grey, calcareous shales with lenticular and semi-nodular, highly bituminous, black limestone. Fossils: *Nummulites, Assilina, Alveolina, Operculina, Ostraea* and gastropods.	300-500 feet.
pockets and thin seams of crushed,	
4. Carbonaceous and pyritous schistose shales; graphitic coal; ironstone shales.	150 feet.
3. Dense, jaspery quartzite, metasomatically replacing the bituminous limestone and ironstone.	0.30 feet.

[230] Gen. Rep. Rec. 62, 154 (1929).
[231] Mem. 51, 258-259 (1928).

2. White, cherty, flaggy limestones.	?
1. Grey, splintery limestone, thin-bedded and slaty varieties alternating with massive, interbedded grey, phyllitic shales; fossils, small, obscure foraminifera and gastropod traces.	200-300 feet.

———Unconformity———

Panjal Trap and Permo-Trias.

Nos. 1 and 2 in position and character appear to be indentical with the Grey Limestone of Hazara (?Cretaceous). Nos. 3 and 4 correspond to Middlemiss' "variegated sandstone and clays with coal". The ironstone bed is in places a haematite shale with flat concretions, and has been used for iron smelting; it probably represents an old lateritised land surface, corresponding perhaps to that which in the Punjab further west separates the Palæocene from the Eocene. No. 5 has yielded *Assilina granulosa, Nummulities* cf. *atacicus, Operculina* sp., ? *Alveolina* sp., *Ostraea and* Naticid gastropoda; it appears to occupy the place of the Hill limestones and Passage beds, since it is followed by the Lower Chharat variegated shale zone, but the correlation of the sequence is not clear.

In the mountain zone between Gurais and the Great range of the Himalaya traversed diagonally by the Burzil stream, are some irregular exposures of Cretaceous-Eocene and Triassic limetones, one of them extending up to the summit of the Burzil Pass. Eroded remnants of a once continuous sheet, they have been preserved, according to Wadia, as trough-folded and faulted outliers in the convolutions of the Salkhala rocks. The largest of these, a Z-shaped outcrop of dark bituminous limestone, with imperfect organic structures, is juxtaposed against the Upper Trias of Gurais along a steep strike fault and has been assigned on lithological grounds to the Eocene by Wadia. To the north of this is a belt of volcanic rocks embracing the head-waters of the Kalapani. The ash beds, tuffs, agglomerates and amygdaloidal traps of this Chechri-Minimarg exposure have already been described.

Some 50 miles E.S.E. of the Burzil Pass an exposure of the same volcanic rocks was found in Dras by Middlemiss to contain thin limestones carrying *Dictyoconoides, Alveolina* and Eocene gastropods.

Further to the southeast and along the same line of strike is a long belt, mainly if not entirely of Tertiary rocks, including volcanic types similar to those of the Dras valley and sediments with Eocene fossils. Between Dras and Kargil the volcanics include augite-porphyrite and diabase, cut by black lamprophyre dykes; at Tasgam (Tashgaon) gabbro and amphibolite appear as small intrusive masses in the diabase-greenstone complex. In this region De Terra reports intense deformation, the rocks, which are associated with lenses of Eocene limestone, being shattered by shear planes. Striding the crestline of the Great Himalaya, this belt of Eocene extends from Kargil in a southeasterly direction for a distance of two hundred

miles, with an average width of 20 miles, along the upper Indus valley. Along the whole of the northeastern boundary, from Kargil to beyond Leh, they rest in unconformable contact with the metamorphic rocks, bosses of which protrude here and there through the more central portions of the Tertiary outcrop.[232] To the west of Leh the dip of the beds is invariably S.W. and varies from 30° to 40° in a remarkably regular and constant manner. Between Khalsi and Leh the lowest beds consist of coarse-grained, sharp, felspathic sandstone, containing a large proportion of grains of undecomposed felspar, and including numerous large more or less rounded boulders of gneiss often several feet in diameter, and angular blocks of an intensely hard "hornstone porphyry" of unknown origin. These beds, which in some places are overlain by carbonaceous shaly beds and in others are missing altogether, are probably of glacial origin and, like the Talchir boulder bed of Upper Carboniferous age fill up hollows in the underlying gneissic floor upon a very uneven surface on which much of them were evidently deposited. No angular unconformity has been detected between these basal beds and the overlying unmistakable Eocene.

The conglomeratic beds are succeeded by orange and brown sandstones, often calcareous, which form the lowest member of the succession in the northwestern part of the belt where the conglomeratic beds are missing. In the neighbourhood of Kargil, *Melania* and a bivalve which is probably a *Unio,* have been found in these sandstones, marking them as fresh-water or estuarine in origin. Ripplemarking is seen in some of the sandstones.

The sandstones are succeeded by green and purple shales, and these are overlain, between Khalsi and Nurla, by a thick band of coarse. blue, shelly limestone containing numerous discs which are probably ill-preserved nummulites. Above this comes a coarse limestone conglomerate containing pebbles of the underlying limestone, succeeded by grey shales and slates. In Ladakh such conglomerates are found in the upper portion of the Eocene, as at Skiu (Skew), but are said to have resemblances to the Laki. The purple sandstones and shales on which they lie are sometimes gypsiferous and contain thin beds of "*Conulites*" (? *Dictyoconoides*) or nummulitic limestone like that found in the Indus valley. Below Paskim (Pashkyum) the purple and green shales have yielded lacerated leaves of *Populus* and palm (*Sabal*), and some *Melania* and *Unio*. These beds may be of Lower Eocene or Palæocene age.

In the Kargil basin De Terra records a conglomerate younger than the Middle Eocene, with pebbles of nummulitic and Triassic limestone, greenstone, purple sandstone, shale and quartzite. Nummulitic limestone is one of the most frequent constituents of these pebbles, occurrring in large sub-angular fragments from 1 to 3 inches across, full of *Nummulites* and *Alveolina* derived from the Eocene limestone (Ypresion-Lutetian) which overlies the Cretaceous flysch in Ladakh.[233]

[232] R. Lydekker. Mem. 22, 99 (1883).
[233] Mem. Connect. Acad., 8, part 2, 37 (1935).

In the sections east of Leh, conglomerates are said to occur near the upper limit of the Tertiary sequence, and to contain pebbles not only of nummulitic limestone but also of certain volcanic beds about to be described. It is possible that the Tertiaries of this belt are not confined to the Eocene, but the whole tract needs a complete re-survey.

In the central portion of the belt, the sedimentary beds are in direct contact with the older rocks along their southwestern margin, but at either extremity they are separated therefrom by a great series of volcanic rocks of a very basic type. These rocks, the youngest Tertiaries of this region, are in the main contemporaneous eruptive products, since they include beds of volcanic ash and agglomerate, but there are also numerous intrusive masses associated with the bedded traps. They are an easterly extension of the Drass volcanics, from the outcrop of which they are however separated by a belt of older rocks. Basic trappean intrusions, evidently connected with the eruptive rocks, are also found in the pre-Tertiary rocks southwest of the boundary ; at Pugha and in the Markha valley south of Leh, these intrusions are composed of pyroxene peridotite (lherzolite) more or less serpentinised. Trap pebbles are found in the higher parts of the Tertiary sequence in the southeastern portion of the belt. To the south of Paskim the width of the trap band is as much as ten miles.[234]

The sedimentary Tertiaries rest on an eroded surface of metamorphic rocks along their northeastern and northwestern boundaries which evidently lie not far from the original limits of deposition in these directions. The southwestern boundary, on the other hand, is marked by disturbance and De Terra speaks of the gypsum-bearing shales of the Eocene as strongly compressed in recumbent folds, whose axial planes are inclined at 40° in a northerly direction ; southwards they gain in steepness towards the Zanskar range.[235] Nevertheless the Tertiary beds are thought to have extended southwards some distance beyond their present limit.[236] Confirmation of this extension is found in the existence of an outlier of nummulitic limestone, first discovered by Dr. Thomson in 1852, on the Singhe La (18,500 feet), and described in 1888 by La Touche as a black fœtid limestone, full of nummulites and resting directly on Palæozoic quartzites, without any intervening littoral deposits. There is, however, no evidence to show that the Eocene sea ever extended continuously from the Indus valley area across what is now the great Himalaya to the area in which the Nummulitics of the Punjab were laid down, though it may have swept over what is now the end of the range in Kashmir. A lithological resemblance between some of the beds of the Tertiaries of the upper Indus valley and those of the Subathu and Dagshai formations has been noticed by more than one observer[237] but is no proof of former continuity. In fact, the general

[234] R. Lydekker. Mem. 22, 111 (1883) ; Rec. 19, 116 (1886) Rec. 21, 154 (1888)
[235] Mem. Connect. Acad. 8, part 2, 39, (1935).
[236] R. D. Oldham, Rec. 21, 156 (1888).
[237] F. Stoliczka, Mem. 5, 343 (1866) ; R. Lydekkar. Mem. 22, 118 (1883).

shallow-water type of the Subathu group and its complete overlay northward by the younger Murrees, indicate a northern limit of deposition of the Tertiaries on the southern face of the Himalaya; such overlap is seen in the lower Chenab, where Murree silts are in direct contact with the more northerly of two large inliers of pre-Tertiary (probably Upper Carboniferous) limestone, while in the case of the more southerly, Nummulitic limestone intervenes.

Among the fossils from the Indus Tertiaries are a *Turbo* and a *Conus*. "*Nummulites ramondi*" and *Assilina exponens* are recorded from the Markha valley and the former also from the outlier of the Singhe La. [238] While the lower beds are of fresh-water origin, the upper are marine, the conclusion following that we have here an old structural depression, occupied at first by a gulf or estuary and later by a river.

Besides the outlier already mentioned, there is one composed of basic traps forming the peaks known as D 24 and D 25 in Zanskar, which may belong to the Dras Volcanics. Some small patches of sandstone and conglomerate, which have been regarded as Tertiary[239], are also found in the Changchenmo valley in eastern Kashmir, but the information concerning them is scanty.

In Hundes, the Tertiaries are composed of schists, phyllites, and crystalline limestones with some distorted nummulite sections, associated with intrusive diorite. Above these rocks come pepper and salt sandstones, very like some of the lower Siwalik beds; their relation to the nummulite-bearing beds has not been observed but is said to be probably one of unconformity. Both formations are highly disturbed, dipping to the northeast, and are unconformably covered by the Pleistocene deposits of the Hundas plain.

A few miles south of the town of Punch, a faulted anticline within the Murree tract, brings up Mesozoic and Eocene rocks, the latter analogous in facies to the Subathu of the Simla area. The succession is as follows:

Muree series.	
White nummulitic limestone with lamellibranch limestone and shale partings	300-400 ft.
Olive and grey shales with thin lenticular coal seams	100 „
Marly shales	20 „
Pyritous and carbonaceous shales with ironstone	25 „
Bauxite and bauxitic clay	6-10 „
Silicified breccia	2- 8 „
Peridotite dykes and sills.	
"Great Limestone".	

[238] Colonel L. M. Davies ventures the opinion that the assilina may prove to be *Assilina granulosa*, which was often mistaken by old observers for the externally similar but larger *A. exponens*. "*Nummulites ramondi*" is a term which in the past has been used to describe *N. globulus* perhaps young forms of *N. atacicus*, and a middle Kirthar form for which the name *N. pinfoldi* is now proposed. Col. Davies suggests that where "*N. ramondi*" is said to be associated with "*Assilina exponens*" by old authors, the beds may prove to belong to the Laki.

[239] F. Stoliczka, Rec. 7, 15 (1874).

The base of the Eocene here appears to be a clastic breccia the original rock of which has been replaced by silica. The bauxite and ironstone are probably old land deposits; the former, from 1 to 3 feet in thickness, grades down into a highly aluminous kaolin and has been traced for a considerable distance.[240] The limestones have yielded *Lucina, Gryphaea, Inoceramus* (?), a large *Ostraea*, and small thin-shelled *Ostraea*, a few gastropods, while the main body of the rock is made up of foraminifera, among which are *Nummulites, Assilina* and *Alveolina*.[241] The coal, best seen at Dandli, is of poor quality and occurs in the form of irregular stringers and in one or two cases as thin seams. These Eocene beds are found fringing two echelonned cores of the "Great Limestone" (probably Permain); in the case of the more southerly core they are confined to the northeastern margin, but in the more northerly they occur with short interruptions along both sides, and at the same time as a small synclinal strip within the outcrop of the older beds. According to Mr. C.M.P. Wright, the Subathus have thus been infolded along the central part of this Great Limestone outcrop, the result being a comparatively regular twin-anticlinal structure with gentle dips to the southwest and somewhat steeper dips to the northeast.[242]

East and northeast of Punch town a band of highly bituminous limestone and calcareous shales about 300 feet in maximum thickness, has been traced for some twenty miles folded or faulted in among the Lower Murree beds.[243] It is possible that the sequence includes the basal Muree zone with nummulites and other fossils derived from the Eocene. These strata lie in an isoclinally folded belt and shew pinching and attenuation. Some of the beds are described as resembling the Chharats, and include lenses or nests of Nummulite Shale with loosely compacted tests of *Assilina exponens, A. granulosa* and *Nummulites atacicus*. In addition, the following beds are recorded: a foraminiferal limestone, which may be black and lenticular, or white, thin-bedded and shelly, with *Ostraea* and other lamellibranchs, and unidentifiable nummulites; red and purple, splintery shales with a band of *Ostraea*; alive shales with limestone lenses, *Ostraea* bands, thick veins of asphalt and other petroleum indications; white sandstone; bituminous limestone with chert bands.

Further southeast, north of Riasi, is another large inlier traversed by the Chenab and situated along the boundary between the Murree and Siwalik series. It comprises a wide core of the "Great Limestone" edged along the northeastern half of its perimeter by a thin succession of olive shales and bands of nummulitic limestone belonging to the Subathu facies of the Upper Nummulitic. The lower portion consists of a coal-seam about $2\frac{1}{2}$ feet thick overlying ironstone and ironstone shales with a pisolitic ironstone at the base.

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[240] Gen. Rep. Rec. 69, 28 (1935).
[241] D. N. Wadia, Mem. 51, 265 (1928).
[242] Rec. 34, 37-38, pt. 7 (1906).
[243] D. N. Wadia, Mem. 51, 265 (1928).

One or two small outlying remnants of the Subathus are seen on the more central parts of the older limestone. The structure is that of a broken anticline, faulted along its steep southwestern scarp.[244] Further along the Chenab to the east is a much smaller inlier of the same rocks, including the Ladhra coalfield.

Chitral.—Below Reshun and south of the town of Chitral a tough conglomerate, which crosses the Chitral river, has been let down by two faults of great throw between Devonian beds on the northwest and the Chitral Slates on the southeast. This Reshun conglomerate, formely suspected of being the equivalent of the Blaini,[245] has been shown to be of Upper Cretaceous or Lower Tertiary age by Mr. Tipper, who has traced both the conglomerate and some associated shales continuously from Reshun as far north as the Khut Pass, where they are not more than 50 feet thick and appear to be thinning out.[246] The matrix of the conglomerate is an indurated, fine-grained, slaty grit or arenaceous mudstone. The pebbles, some of them over 3 inches across, vary much in size and colour; many are rounded, a few are angular, but the majority are sub-angular, consisting of limestone, slate, sandstone, quartzite and white quartz.

C. THE HIMALAYA FROM THE SIMLA HILLS TO GARHWAL.

The Subathu series.—The Tertiaries of the outer Himalaya comprise in the first place a narrow zone of the upper members of the system, extending the whole length of the chain, and continuous at the surface, except for a stretch of about 70 or 80 miles at the foot of the Sikkim and western Bhutan hills, where gaps in the continuity occur, one of them of 36 miles, caused by concealment either beneath overthrust older beds or under a great accumulation of recent deposit. Northwest of the Ganges the Tertiary area begins to widen, and lower beds come in, till in the extreme northwest, beyond the Jhelum, there is a comparatively full representation of the system. It is only that portion of the Himalayan Tertiary which lies beyond the western frontier of Nepal that has been examined in any detail, the best known areas being the hills below Kumaun and Garhwal, and the section south of Simla.

Of the Nummulitic series, the Lower division has not been recognised in the Himalaya except at the Kashmir end of the range. Elsewhere the Eocene is represented by a series, named after the military hill-station of Subathu below Simla, where it is well exposed. The exact relationship of the Subathu to the Chharat is not yet clearly known, but the former in all probability includes nothing older than the Kirthar and is thought to range up into the Oligocene. Assuming the Nummulite Shale together with the under-

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[244] R. R. Simpson, Mem. 32, 196 (1904).

[245] C. A. McMahon. Q.J.G.S., 56, 337-367 (1900); McMahon & Hundleston. Geol. Mag., Dec. 4, Vol. 9, 3-8 (1902).

[246] Gen. Rep. Rec. 54, 56 (1922).

lying Kohat Shale to represent the middle Kirthar, the bulk of the latter series would appear to be absent from the Punjab where the Nummulite Shale is the highest Eocene bed known. It would seem, therefore, that these missing higher beds begin to make their appearance in Kashmir in the form of the lower portion of the Subathu, their appearance being accompanied by the disappearance of the Lower Nummulitic and most, if not all, the Upper Nummulitic of the Punjab succession.

The Subathu beds are succeeded by two groups, the Dagshai and Kasauli, which are the equivalent of the Murree series of the north-west. The term Sirmur series has been applied to the three groups, Subathu, Dagshai and Kasauli, but is unnecessary and artificial in view of the facts that, while there is no decided break between the top of the Kasaulis and the succeeding Siwaliks, a considerable unconformity of palæontological as well as stratigraphical character,[247] is thought to exist between the top of the Subathus and the base of the Dagshais, and also that, while the Subathus are of marine origin, the Dagshais and Kasaulis are lagoonal fluviatile deposits.

In the hills below Simla the Subathus, with the Dagshais and Kasaulis (Miocene), appear from below more recent deposits north of Bilaspur on the Sutlej and, rising into the higher ground of the Lesser Himalaya, extend for some eighty miles southeastwards till they disappear twelve miles beyond Nahan. They are also seen in a tectonic inlier in the Shali region northeast of Simla. To the east of Nahan lenticles of fossiliferous limestone in the Dagshai rocks of the Tons river suggest that Subathu beds may be present there.[248] The series is exposed in two more tectonic "windows" between Dehra and Rikhikesh and reappears as a very thin belt southeast of the Ganges; at a distance of nearly forty miles in the same direction from the latter river, the beds have been recognised by Middlemiss but are here extremely thin and presumably on the point of dying out.[249] The Subathus were not encountered by Medlicott in his traverse across part of Nepal and are not known to occur in the Himalaya east of longitude 79° E. To the north of Bilaspur, the beds extend down into the foot-hills where they are largely covered by younger deposits and are less severely folded; in this direction they probably stretch for 45 miles into Mandi State.

The Subathu beds are for the most part confined to the lower slopes of the lesser Himalaya, mostly below the 4,000-foot contour line. On the Tibetan side of the main Himalaya, Eocene rocks are again seen and will be described separately.

The Subathus of the Simla area and Garhwal are everywhere highly disturbed and have shared in the over-folding thrusting, and shearing to which the Himalayan rocks as a whole have been

[247] Gen. Rep. Rec. 41, 83 (1911).
[248] J. B. Auden. Rec. 71, 416 (1936).
[249] Mem. 24, pt. 2, map (1890).

subjected. Below Simla and Chakrata, not only have older rocks mostly the Infra-Krol but sometimes the Jaunsars been thrust over the Subathus, but all the beds as well as the thrust-plane itself have been folded again subsequent to the thrust by continued compression, the additional folding having been accompanied by further faulting. The structure, therefore, is highly complex and the Subathus, although generally unmetamorphosed, have suffered changes locally into epi-type rocks. Locally the shales have been so metamorphosed as to be indistinguishable from the much older Blaini (Upper Carboniferous).[250] The rocks stratigraphically underlying the Subathus are believed to be the Upper Tal (? Cretaceous), but the two formations have not yet been observed in contact.

The Subathus comprise olive-green and purple, oily-looking, gypseous shales, with some subordinate lenticular bands of impure limestone and sandstone, the latter occurring principally near the top of the formation. The shales are characterised by minute, irregular, ramifying, joints, and by planes of movement often filled in with calcite. The limestones may be shelly, or they may be unfossiliferous, sheared and full of calcite veins. The sandstones are green and white in colour, the green being due to the presence of chlorite; a rare shaly variety is ripple-marked. Occasionally some of the arenaceous beds have been altered to iron-stained quartzites.[251] Nummulites are seldom seen and well preserved fossils are rare, the shelly limestones being made up mostly of broken oysters. From Subathu come the Kirthar forms, *Ostraea multicostata* Desh., *O.* (*Liostraea*) *flemingi* d'Arch. & H., *Cardita mutabilis* d'Arch. & H. and *Corbula* (*Bicorbula*) *subexarata* d'Arch & H.[252] Some 49 species of fossils from this group were described by d'Archiac & Haime in 1853-4 and include the nummulines:

Alveolina ovoidea d'Orb.,
Nummulites scaber Lam., (*N. laevigatus*) (Brug.); (includes *N. acutus* of Sowerby),
Nummulites obtusus Sow.,
Nummulites perforatus (de Montf.) (megalospheric form of *N. obtusus*).,
Nummulites beaumonti d'Arch. & H.,
Assilina exponens Sow.,
Assilina spira de Roissy.

If Nummulites beaumonti is a correct determination, and there is reason to believe that it may be, the conclusion follows that the Subathu at least includes the Upper Kirthar. Since the determinations of the mollusca made by d'Archiac and Haime were based in the majority of cases upon internal casts, they are not very reliable.[253] Some recent identifications by H. E. Vokes[254] from two

[250] Gen. Rep. Rec. 66, 125 (1932).
[251] J. R. Auden, Rec. 67, 387 (1933).
[252] L. R. Cox, Trans. Roy. Soc. Edin., 57, 33-34 (1934).
[253] d' Archaic & Haime. Animaux Fossiles de l' Inde, p. 363 (1853-54).
[254] Amer. Mus. Novit, No. 964 (1937).

localities northwest of Simla, representing a lower zone and a middle zone, are as follows:

Lower zone (21 miles N.W. of Simla and 5 miles N.W. of Arki):

LAMELLIBRANCHIATA.

Euphenax coxi Vokes,
Ostraea (*Liostraea*) cf. *roualti* Mallada,
Cardita sp.,
Cardium (*Discors*) *simlaensis* Vokes.,
Panopaea cf. *intermedia* (Sow.).

GASTROPODA.

Gosavia humberti (d'Arch. & H.),
Gosavia (?) *multidentata* (d'Arch. & H.).
Conus sp.,
Cf. *Involuta daviesi* Cox,
Lyria browni Vokes (apparently=d'Archiac & Haime's "*Voluta jugosa* Sow. var a", also said to occur in the Gaj of Cutch and Sind),
Cassidaria cf. *desori* d'Arch. & H.,
Campanile sp.,
Ampullella nuttalli Cox,
Turbo (?) sp.,
Middle zone (26 miles N. W. of Simla and 6 miles N. W. of Arki):

LAMELLIBRANCHIATA.

Cardita mutabilis d'Arch. & H.

GASTROPODA.

Terebellum sp.,
Seila stracheyi (d'Arch. & H.),
Cepatia cepacea Lam.

The bottom bed of the Subathu formation is well seen at Subathu but is of limited distribution ; it is a lateritic rocks containing pisolitic grains of iron oxide. In the shaly beds immediately overlying the ferruginous laterite at Subathu is a seam of impure coal, also of inconstant occurrence. Infrequently there are found conglomerates made up of a matrix of calcareous sandy mud, in which are set fragments of pale coloured, micro-crystalline limestone of unknown derivation.

In the abnormal metamorphic facies of the Subathu, seen near Kalka and one or two other localities, the purple and green shales have become phyllitised and veined with quartz, and the carbonaceous shales converted to dirty bleaching slates exactly similar to examples in the Infra-Krols ; greenstones are frequent in one of these localities.

East of the Ganges at Hardwar there is a very thin band of the Subathus locally repeated by folding and sandwiched in between older rocks. The base in some places is a ferruginous pisolite. This passes up into grey and sometimes slightly purple shales and sandy beds with earthy calcareous nodular beds and strings of a puper, dark blue-grey limestone ; higher up the limestones disappear and the beds consist of sombre purple, grey and greenish-grey shales, capped by some purple gritty bands which are fore-runners of the

Dagshais. The shales are described by Middlemiss as in places much hardened and not very different from the much older slates with which they are folded and with which they seem to have become welded.[255] The purer limestone contains nummulites and other foraminifera, mollusca and fragmental vertebrate remains.

Nearly 40 miles E.S.E. of Hardwar the same thin band of Subathu beds has been recognised, but there is good reason to conclude that the deposit dies out within a comparatively short distance of this locality.

The salt deposits of Mandi.—The salt deposits of Drang and Guma (Gama) in Mandi State have been worked for the past four centuries; they are closely connected with a limestone at one time thought to belong to the Krol formation (? Permo-Trias), but both Sir Henry Hayden and Captain R. W. Palmer have expressed the opinion that the salt and associated marls are sedimentary deposits of Subathu age.[256] Although very much less pure, the salt rock of Mandi resembles that of the Punjab Salt Range in its reddish colour, in its potassium content, and in its association with a bright red marl, which sometimes contains bituminous beds. Potassium chloride is a common constituent, especially in the lighter coloured bands, at both Drang and Guma. The salt rock is opaque and dark purplish in colour, with 25 per cent. of earthy impurities;[257] in it are disseminated pebbles of quartzitic sandstone, limestone and other rocks. At Guma the horizontal upper surface of the salt is merely a solution surface and not a stratigraphical boundary with the superjacent eight feet of red, pebbly marl heavily banded with haematite and specular iron ore; the latter is but a residual deposit formed by the removal in solution of the soluble chlorides from the salt rock, and is a useful indicator of the presence of hidden salt. Serpentinised trap and dolomite are associated with these supposed Subathu beds;[258] at Guma a limestone underlies them. The saliferous zone, but not the workable salt, is nearly continuous from Guma to Drang, the salt at Guma occurring in a large pocket.

Tectonic "inliers".—The very interesting discovery of Subathu beds in the hilly country between the Shali peak—a peak some 9 miles northeast of Simla and Matiana was made by Sir Henry Hayden.[259] Other sporadic outcrops of the same series were subsequently found to the east and south of the peak. Further work by West has shown that the Subathu outcrops occur as thin, irregular, intermittent bands among both older and younger rocks, all of which are exposed in a tectonic "window" which here pierces the overthrust Chail beds. The rocks beneath the window have been severely folded in places and their boundaries are not always

[255] Mem. 24, 88 (1890).

[256] Punjab States Gazetteers, Vol. 12A, Mandi State, p. 4, (1904); Gen. Rep. Rec. 53, 12 (1921).

[257] H. B. Medlicott. Mem. 3, pt. 2, 60 (1864).

[258] Q. J. Geol. Min. & Met. Soc. Ind., Vol. 1, 165 (1926).

[259] Gen. Rep. Rec. 50, 8-9 (1919); Gen. Rep. Rec. 51, 9 (1920).

easily indicated. The Subathus have been found in contact with every variety of bed belonging to the Madhan Slates (? Mesozoic) and, in the opinion of Pilgrim and West, must have been deposited on a much denuded surface of these slates.[260] In some places the Subathus are overlain by younger Tertiary sediments of approximately Miocene age (Dagshais); elsewhere their upper boundary is in contact with the overthrust Chail, a formation of pre-Cambrian or early Palaeozoic age. The Madhan Slates, with the underlying and more extensively exposed Shali series of possibly Mesozoic age, together with the overlying Tertiaries, have all been overridden by the Chail *nappe* along what has been called the Shali Thrust.[261]

The beds under consideration present a typical Subathu appearance, and include a pisolitic laterite, olive and red shales, and shaly limestones with very badly preserved fossils; most of the latter are lamellibranchs, some chaetopod worm tracks belonging to the genus *Serpula* have been recognised, and a few nummulites, so far as determination is possible, are thought to be Subathu forms.[262] It is to the south of the Shali peak, around Katnol that the Subathu beds are accompanied by some Dagshai sediments.[263]

Perhaps the tiny outcrop of Sabathu limestone and shales seen among the splintery Simla Slates near Dochi, southwest of Jutogh, may be another window of these deposits.

Two similar tectonic windows have been recognised by Auden between Dehra and Rikhikesh in Garhwal. Each of these is 6 or 7 square miles in area and occurs along an anticlinal axis. In the central parts of the windows occur ancient slates belonging to the Simla Slates series, generally with steep dips. Resting on these old rocks, sometimes as isolated cappings, more typically as a border to the windows, are the Nummulitic shales and limestones together with blocks of highly shattered quartzites, the surfaces of which have been glazed by friction. Over the Nummulitics and Simla Slates have been thrust rocks (unmetamorphosed Chandpur beds). belonging to the Krol *nappe*: These Tertiaries have evidently been subjected to violent shearing stress, and the Nummulitic shales in one of the windows have been converted into what Auden calls a "pseudo-schist".[264]

D. TIBET.

Both the Cretaceous and Eocene are well exposed in the Kampa ridge, in the neighbourhood of Kampa-dzong, in southern Tibet (Tsang and U), and together constitute a system to which Sir Henry Hayden has given the name of Kampa. The Cretaceous succession

[260] Mem. 53, 121 (1928).
[261] W. D. West, Rec. 74, Pl. 6 (1939).
[262] Gen. Rep. Rec. 50, 9 (1919).
[263] Gen. Rep. Rec. 71, 72 (1937).
[264] Rec. 71, 418 (1937).

is followed by beds which were classed by Professor Douvillé partly as Danian and partly as Eocene. Hayden had at first included the unfossiliferous Ferruginous Sandstone tentatively as Danian and the rest as Eocene, suggesting later that the sequence from the Ferruginous Sandstone to the top of the Dzongbuk Shales (Spondylus Shales) might represent the Lower Ranikot.[265] This suggestion was not far from the truth, for the three stages above the Ferruginous Sandstone have since been found by Col. Davies to contain typical Upper Ranikot nummulites; the Ranikot affinities of the other fossils have been marshalled by Dr. Cotter.[266] The Palæocene-Eocene succession in this region, therefore, is as follows:

	8. Dzongbuk shales.	
	7. Alveolina Limestone.	
	6. Sandy and micaceous shale, with flaggy sandstone, and a narrow calcareous band near the base;	150 feet
	5. Orbitolites Limestone.	50 ,,
Upper Ranikot.	4. Spondylus Shales.	150 ,,
	3. Operculina Limestone.	150 ,,
	2. Gastropod Limestone	300 ,,
	1. Ferruginous Sandstone	200 ,,

The topmost Cretaceous limestone (the Tuna limestone) is described as invariably overlain by about 200 feet of coarse, unfossiliferous, sandstone, gritty and conglomeratic in parts and frequently highly ferruginous. The change from the one formation to the other is not particularly abrupt since the uppermost layers of the limestone are sandy and sometimes include bands of sandstone. There is no apparent unconformity and the change to shallow-water conditions must have been comparatively rapid and the interval of time between the end of the Masozoic and the beginning of the Tertiary is very short. In the hills around Kampa-dzong the Ferruginous sandstone contains small segregations of iron ore.

The Ferruginous sandstone passes up rapidly into the Gastropod limestone which is at first thin-bedded but higher up becomes a hard, dark, massive rock full of badly preserved gastropod casts; rather above the middle of this mass occurs a 40-foot band of unfossiliferous shale. The Gastropod limestone is found in both the ridges which extend from Kampa to Tatsang; in the more southerly of the two it occurs in normal sequence, but in the northern ridge it and other beds have been thrown above younger strata by an important strike fault which is at least 20 miles long. The Gastropod limestone, which is exposed on the Tuna ridge but is best seen in the gorge about 2½ miles above Kampa-dzong, has yielded the following fauna, the foraminifera being more conspicuous in the lower horizons.[267]

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[265] Mem. 36, 178 (1907).

[266] Rec. 59, 410 (1926).

[267] Prof. Douvillé, Pal. Ind., New Ser. Vol. 5, No. 3, (1916): Col. Davies. Pal. Ind., 24 No. 1, 69 (1987) L. R. Cox, Pal. Ind. 24, No. 1, 71 (1987).

ALGAE. (Douvillé)

Cymopolia sp.,
Larvaria sp.

FORAMINIFERA. (Davies)

Miscellanea stampi (Dav.),
Miscellanea miscella (d'Arch. & H.),
Lockhartia haimei (Dav.),
Lockhartia conditi (Nutt.),
Lepidocyclina (*Polylepidina*) *punjabensis* Dav.,
Bigenerina sp. (apparently the same species as that found in the Khadrabad Limestone of the Salt Range),
Verneuilina sp. (ditto.),

HYDROZOA. (Douvillé).

Delheidia haydeni Douv[268] (numerous at the base, where it is associated with many algæ and with *Velates perversus*).

LAMELLIBRANCHIATA. (Douvillé)

Cardita (*Venericardia*) sp.,
Lucina sp.,

GASTROPODA. (Cox.)

Megalocypraea ranikotensis Schild. (*Gisortia depressa* (Sow.) of Douville.[269] close to the Ranikot form *G. tuberculosa* Duclos.),
Eocypraea cf. *feddeni* (Vred.) (=cast; Douville's Ovula cf. *ellipsoides* d'Arch. & H.),
Terebellum distortum d'Arch. & H. (Upper Ranikot and Laki, Sind: Dhak Pass beds Salt Range.),
Gosavia humberti (d'Arch. & H.) (=Douvillé's *Voluta* (*Gosavia*: *Aulica*) *salsensis* d'Arch. & H. (Laki of the Salt Range, Laki and Kirthar of Sind),
Aporrhais (*Lambis*) *goniophora* (Bellardi) (Douvillé's *Chenopus tibeticus* Douv.; Upper Ranikot, Sind; Mid.-Upper Eocene, Europe, etc.),
Hippochrenes cf *amplus* (Sol.) (Douvillé's *Chenopus* (*Hippocrene*) *columbarius* (d'Arch. & H. Salt Range; Laki Sind; Kirthar, N. W. Frontier),
Cerithium (*Campanile*) cf. *breve* Douv. (probably a new species; *C. breve* is a Persian form),
Velates perversus (Gmel) var. *noetlingi* Cossm. & P. (Douvillé's *V. tibeticus*; Upper Ranikot, Salt Range and elsewhere).[270]

OSTRACODA.

Bairdia subdeltoidea (Münst.).

CEPHALOPODA.

Nautilus pseudobouchardi Spengl. (very close to *N. labechei* d'Arch. & H. from the Laki of Sind, found in the Ariyalur of Trichinopoly).

The Operculina limestone is a shaly limestone, always markedly nodular and for that reason forming a characteristic and easily

[268] Regarded by A. Silvestri as identical with *Bradya tergestina* Stache, a Danian species of either hydrozoon or foraminifer from Istia and Dalmatia (see Rivista ital. di. Pal., Vol. 30, 17-26 (1924); Abhandl. d.k.k. geol. Reichsanst., Vol. 13, pl. 6, figs. 24-28 (1889); Dolfus concludes that the Tibetan fossil is not a Delheldia and proposes a new generic name, *Robertella* (Rev. Critique de Palaeozool, p. 39 (1917).

[269] Pal. Ind., New Ser. 24, No. 1, 71 (1937).

[270] see Cox, Trans. Roy. Soc. Edin, 57, 33 (1934).

recognised horizon, the nodules harder and more compact than the interstitial shaly matter, standing out on the cliff face and covered with small dark specks which are weathered out foraminifera. Both in fauna and lithology this stage bears a strong resemblance to the Khairabad limestone of the Salt Range. It caps both the ridge north of Kampa-dzong and the ridge northwest of Tuna; in such exposed situations it takes on the character of a nodular calcareous shale rather than a limestone, a result due to the softness of the rock and its inability to resist the severe disintegrating forces of the Tibetan climate. The Operculina limestone contains foraminifera in large numbers, chiefly *Operculina* and *nummulines,* but few other fossils; *Velates perversus* so characteristic of the subjacent stage, is not infrequent in this. The following species have been identified, the foraminifera by Col. Davies, and the rest Prof. Douvillé:

FORAMINIFERA.

Nummulites sindensis (Dav.),
Nummulites thalicus, var. *gwynae* Dav. (probably the megalospheric form of *N. Sindensis*).
Operculina cf. *canalifera* d'Arch.,
Operculina cf. *salsa* Dav.,
Operculina subsalsa Dav.,
Miscellanea stampi (Dav.),
Miscellanea miscella (d'Arch. & H.),
Lockhartia haimei (Dav.),
Lockhartia newboldi (d'Arch. & H.),
Lockhartia conditi (Nutt.),
Dictyoconoides cf. *flemingi* Dav., ...
Lepidocyclina (*Polylepidina*) *tibetica* (Douv.) ("*Lepitorbitoides*" cf. *Douvillé*),
Lepidocyclina (*Polylepidina*) *punjabensis* Dav.,
Bigenerina sp.,
Verneuilina sp.

LAMELLIBRANCHIATA.

Corbis cf. *lamellosa* Lam.,
Chlamys ? sp.

GASTROPODA.

Lyria ? sp.,
Cerithium (*Campanile*) cf. *breve* Douv.,
Cerithium (*Campanile*) *brevius* Douv.,
Ampullina (*Pachycrommium*) *flemingi* (d'Arch. & H.) (Douville *Natica* cf. *flemingi* d'Arch. & H.; recalling *Ampullospira adela* C. & P. of the Ranikot).[271]
Velates perversus (Gmel.).

OCTRACODA.

Bairdia subdeltoidea (Münst.),
Cythere sp.

CEPHALOPODA.

Nautilus pseudobouchardi Spengl.,
Nautilus cf. *rota* Stol. (found in the Cretaceous of the Coromandel coast).

[271] Believed by Vredenburg to be identical with a Laki from the Salt Range (Rec. 59, 413 (1926).

The Operculina limestone is followed by about 150 feet of fine-grained, greenish, grey and black shale, full of small nodular masses or marcasite. It is exposed on the right bank of the Kampa stream, about a mile above the fort, where some poorly preserved fossils, chiefly lamellibranchs and gastropods, have been collected. *Sponhylus* is the predominating genus, gastropods are represented chiefly by the persisting *Velates*, and foraminifera like those of the bed below occur in calcareous bands in the shale. The following forms have been determined in these Spondylus Shales, the foraminifera by Col. Davies and the rest by Prof. Douvillé:

FORAMINIFERA.

Nummulites sindensis (Dav.),
Operculina cf. *canalifera* d'Arch.,
Operculina subsalsa Dav.,
Miscellanea stampi (Dav.),
Miscellanea miscella (d'Arch. & H.),
Lockhartia haimei (Dav.),
Lockhartia newboldi (d'Arch. & H.),
Lockhartia conditi (Nutt.),
Lepidocylina (*Polylepidina*) *tibetica* (Douv.),
Lepidocylina (*Polylepidina*) *punjabensis* Dav.,
Verneuilina sp.

ECHINOIDEA.

? *Cyphosoma* sp.

LAMELLIBRANCHITA.

Spondylus rouaulti d'Arch. (present in the Upper Ranikot of Sind and Baluchistan ; probably also in the Laki),

Chama sp.

OSTRACODA.

Velates perversus (Gmel.). var. *nœtlinoi* Cossom. & P.
? *Drepanochilus fusoides* d'Arch[272] (The Ranikot form of *Rimella fusoidasi*).

GASTROPODA.

Bairdia subdeltoidea (Münst.).

The next stage is a limestone band, about 50 feet thick, in the Gastropod limestone, the Operculina limestone and the Spondylus Shales, all show a striking resemblance to that of the Khairabad limestone and Col. Davies suggests a correlation of them all with the lower parts of this Salt Range stage, and the Ferruginous sandstone with the Dhak Pass beds.[273]

The faunas of the three Ranikot stages just described, *i.e.*, of the lower argillaceous layers of which are found large specimens of *Orbitolites complanatus* Lam. Higher up occurs *Alveolina oblonga*

[272] According to Vredenburg this from differs from d'Archiac's type *Rimella fusoides* from the Ranikot but corresponds to an undescribed species very abundant in the Laki (Rec 59, 413 (1926).
[273] Pal. Ind., New Ser., 24, No. 1, 70 (1937).

d'Orb. Both these foraminifera are Laki forms, their presence indicating a marked change in the fauna. Under the microscope the rock is seen to be composed largely of *Orbitolites, Alveolina* and *Miliolina* (*Quinqueloculina*). Another fossil identified by Douvillé from this Orbitolites limestone is the lamellibranch, *Vulsella* (*Vulsellopsis*) *legumen* (d'Arch. & H.), a form found in both the Laki and Kirthar.

At the top of the sequence is a sandy and micaceous shale, with flaggy sandstone, and a narrow calcareous band at the base. About 150 feet of these beds are seen but they are cut off abruptly by an important strike fault which throws them down beneath older Tertiary horizons. The calcareous band, about 80 feet above the base, has yielded lamellibranchs and gastropods, while from the shales have been collected a few lamellibranchs. The only species determined are *Ostraea* (*Liostraea*) *flemingi* d'Arch. & H. and *Coniscala tibetica* Douv., the former of which has been found in the Middle Kirthar of Cutch, and in the Laki beds of the Salt Range.

In the pass known as the Dzongbuk La, between the Kampa and Tatsang valleys, the Operculina limestone is overlain by beds which Hayden was unable to examine in detail but which probably include the sandy and micaceous bed of stage 6. Above these is a limestone, dipping like the rest of the beds at a high angle to the north and composed almost entirely of *Alveolina.* Above this is a considerable thickness of dark shale the Dzongbuk shales which is faulted against an overfolded syncline involving the Ferruginous sandstone and underlying Cretaceous beds.

Of this Tibetan sequence stages 1 to 4 may with confidence be assigned to the Ranikot, No. 1 representing either the sub-aerial deposits of the Lower division of that series, or the Dhak Pass beds of the Salt Range. Beds 5 and 6 cannot be closely correlated with any stage found in the Salt Range. The Alveolina limestone has every appearance of corresponding to the Laki limestone and the overlying Dzongbuk Shales may be the equivalent of some of the higher horizons of the Gahzij Shales, *i.e.*, of some part of the Lower Kirthar; this would make the Orbitolites limestone the approximate equivalent of the Meting limestone and stage 6 that of the Meting Shales.

In the neighbourhood of the Cho Lamo, north of Sikkim, Sir Joseph Hooker records the presence of conglomerates, slates, earthy red clays and a compact blue limestone "full of encrinitic fossils and probably nummulites.[274]

Palæocene rocks, in the form of reddish grey, calcareous sandstones, have been recognised by de Terra and Bohn in the western Kuen Lu, and have yielded *Ostraea bellovacina*, var. *trinkleri*, *Membranipora* sp. and *Cliona* sp.[275] Lower, Middle and Upper stages of his group are said to be present in different parts of the range.

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[274] Himalayan Journ., Lond. 1855, 2, 156, 177.

[275] Geogr. Review, 24 (1934).

Everest area.—Further west, in the Mount Everest area, the Kampa system, including both Cretaceous and Eocene (see p. 1324), occurs in much compressed synclines and does not exhibit the magnificent sequence of the Kampa-ridge. Not only is the succession obscured by faulting and interrupted by alluvial covering, but the fossils in the rocks have ben destroyed or damaged by shearing.[276] Eocene beds have been recognised in the Tsipri ridge, some 45 miles north of Everest summit, and again further west, on the other side of the Phung Chu, interruptedly between Gutso and the Yao La. In the latter area the Ferruginous Sandstone takes the form of a massive, pink and white quartzite, 100-150 feet thick; this bed shows as high a degree of metamorphism as any pre-Cambrian quartzite, and weathers into large blocks. The beds below it are brown shales; above it come the highest beds exposed in the section, consisting of almost unaltered, blackish grits with dicotyledonous fossil wood.

The Tsipri ridge, according to Heron, is an isosyncline, dipping north at from 20° to 40°, but affected by minor corrugations, and becoming recumbent towards the east: its northern margin shows considerable alteration caused by the granite intrusions of the Northern Range. In the Tsipri ridge the sequence is somewhat fuller than it is in the Yao La sections. The Ferruginous sandstone is less indurated and contains abundant spherical concretions of iron oxide; along certain levels it is finely conglomeratic, with pebbles the size of buck-shot and composed of transparent quartz, quartzite of various colours, and white chert. The Ferruginous sandstone both overlies and underlies regular bedded limestones, the whole sequence forming a minor scarp. Above these beds come massive, grey thick-bedded limestone containing abundant *Alveolina* and *Operculina* and alternating with massive, white, very fine-grained, unfossiliferous varieties, as well as thin-bedded limestones: this group of beds forms a bold scarp and would appear to include the *Operculina* limestone stage. Indications point to a shallower water succession in the Everest area than obtains at Kampa.

In the syncline which occupies a lower portion of the Phung Chu, south of the Tsipri ridge, the Ferruginous sandstone is the only member of the Eocene present.

E. ASSAM AND THE COROMANDEL COAST.

Assam.—A narrow belt of Eocene rocks is exposed in the southern foothills of the Shillong plateau throughout the greater part of its length from west to east and continues northeastwards through the north Cachar hills and the Mikir hills as far as a small tributory of the Dhansiri, the Boro Neoria; beyond this it is apparently overlapped by younger Tertiary beds. In the Shillong plateau the Eocene beds with the exception of the basal member, thin out very rapidly northwards. That this thinning out is an original feature

[276] A. M. Heron. Rec. 54, 224 (1922).

of deposition and not a result of recent denudation is shown by the fact that the base and summit of a bed are sometimes recognisable in two compared localities; a limestone about 1,000 feet thick in the foothills near the Khasimara river is found to have dwindled to 500 feet nine or ten miles to the north in the outlier of Mawsynram.[277] Coal is found in the more northerly occurrences but not in the south.

The most recent account of the Assam Tertiaries is by Mr. P. Evans,[278] who finds that the Eocene is comprised in what he has termed the Jaintia series and perhaps the basal unfossiliferous stage of the overlying Barail series. As most of the latter is of Oligocene age it will be more convenient to describe all its stages in a later chapter. With the Eocene Fox would also include the Cherra Sandstone, formerly grouped with the underlying Cretaceous, together with the coal of the Garo Hills, north Cachar and Mikir Hills and much of that found in the Khasia and Jaintia Hills.[279] In agreement with this is the admission by Medlicott that the only surface of sharp contrast in the sedimentary beds at Cherrapunji occurs at the base of the Cherra Sandstone.[280] In this chapter, therefore, attention will be confined to the following sequence·

Jaintia series	Kopili stage. Sylhet Limestone.

Cherra Sandstone and its equivalents.

Not only does the Eocene as a whole thin and die out towards the north, but there is reason to think that the younger stages die out sooner than the older in this direction. While in Cretaceous and early Eocene times the sea encroached on to the Shillong plateau land-mass from south to north, the opposite seems to have occurred and a retreat of the waters to have set in after the deposition of the Sylhet Limestone in a sea which covered most of the plateau, though this still requires definite proof; it is, therefore, the older stages of the Eocene which have been left in outliers on the plateau to the north by the southward retreat of the sea.

It is in these primitive little basins on the plateau that the coal is found. Much of the mineral itself has a persistent character throughout, being compact and splintery, with a smooth conchoidal fracture, and emitting a dull wooden sound when struck; it has the additional peculiarity of containing numerous specks and small nests of fossil resin, and a considerable quantity of sulphur in the form of iron pyrites.[281]

A very persistent member of the series is the Cherra Sandstone at its base, underlying the Sylhet Limestone. While most of the rocks in the southern scarp of the plateau thin out and disappear

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[277] R. W. Palmer, Rec. 55, 162 (1923).
[278] Trans. Min. & Geol. Inst. Ind., Vol. 27, 155-260 (1932)
[279] Gen. Rep. Rec. 69, 84 (1935).
[280] Mem. 7, 169 (1869).
[281] V. Ball & R. R. Simpson, Mem. 41, 26 (1913).

northwards, the Cherra band persists and oversteps the fossiliferous Cretaceous.[282] This is well seen near Mawbehlarkar where the latter dies out; in the neighbouring coalfield itself the Cherra Sandstone rests on a conglomerate believed to be the solitary representative of the Cretaceous. Further south there intervene between the two some 400 feet of sandstones, the topmost of which may have been contemporaneous with that portion of the conglomerate deposited at Mawbehlarkar. The unconformable relationship of the Cherra Sandstone to the underlying Upper Cretaceous can be seen in the eastern edge of the Cherrapunji plateau.[283] Normally the Cherra Sandstone consists of about 200 feet of coarse sandstone, unfossiliferous except for some vague non-carbonaceous, stem-like, vegetable impressions; it is often felspathic especially in its basal portions. The lower part of the band consists usually of a coarse, soft, felspathic grit, in which small pebble beds are sometimes developed. In the northern hills this passes up into a finer, white, crumbling sandstone, overlain by a white clay band two or three feet thick and in places carrying a considerable number of plant stems. Sometimes the basal horizon is composed of a peculiar detrital rock formed from the rotten underlying crystallines. Some of the old valley accumulations consist of such rotten granite overlain by a uniform deposit of felspathic grit; the decomposition of the granite took place in pre-Cretaceous times and the old land surface was lowered beneath a sea so calm that the rotten rock was barely disturbed and shows no effects of running water. In some sections lumpy, mottled, sandy clays or earthy sandstones are features of the lower part of the Cherra band. Palmer records a thickness of 300 feet for this band in the northern hills.

This stage frequently forms a terrace or ledge along the southern part of the plateau, such as that upon which Cherrapunji is built. In the Garo Hills, west of Tura, the coal-bearing Cherra sandstones are associated below with a bed of kaolin resting upon kaolinised gneiss. Here Dr. Fox has found the Cherra stage to be 600 feet thick, with two coal seams, while the Sylhet limestones and shales total some 200-550 feet and the Kopili beds 1,000-4,000 feet.[284] The coal of Darang ("Daranggiri") and Rongrenggiri, north of the Tura range in the Garo Hills occurs in Cherra sandstone brought into this position by block-faulting; the former includes a 6-foot seam of good quality coal.[285] The Um Rileng coalfield, seven miles northwest of Shillong, also belongs to this horizon and probably represents a northerly outlier of the coal at Mawbehlarkar (Mao-beh-larkar). The latter is a tiny field which for many years supplied the neighbouring hill-station of Shillong with coal.[286] The Um Rileng coal contains fossil resin and its associated beds include basal lithomarges lying almost flat on kaolinised gneiss along the foot of a great ridge

[282] Gen. Rep. Rec. 69, 84 (1936).
[283] Gen. Rep. Rec. 73, 78 (1938).
[284] Gen. Rep Rec. 72, 90 (1937).
[285] Gen. Rep. Rec. 71, 35 (1936).
[286] V. Ball & R. R. Simpson, Mem. 41, 26 (1913).

of conglomerates and quartzites belonging to the Shillong series. These ancient rocks may be separated from the coal-bearing beds which are not less than 500 feet thick, by a fault, or the ridge may represent an old cliff against which the coal-bearing deposits accumulated. The coal of the Garo and Khasi hills accumulated not far from the coast, possibly in brackish-water lagoons, as Dr. Fox suggests.[287] When of good quality this coal is associated with strata which are devoid of marine fossils but which pass southwards into richly fossiliferous marine sediments devoid of coal. This coal is characterised by impressions of dicotyledonous plants.

In the Tharia stream section, forming the lower portion of the Eocene are about 900 feet of strata made up of four limestones totalling 650 feet separated from each other by sandstones. The lowest limestone is practically devoid of fossils and grades downwards into an impure earthy limestone and calcareous shales from which several Cretaceous fossils have been obtained. Between the lowest of the set of four limestones and the next above is a considerable thickness of plant-bearing sandstone ; A. M. N. Ghosh prefers to regard this limestone and the sandstone immediately above as filling the place of the Cherra Sandstone, while the upper three limestones with the intervening sandstones he would correlate with the Sylhet Limestone.[288]

The Jaintia series, according to F. E. Eames, coincides approximately with the Lower and Middle Kirthar, *i.e.*, with the Lutetian ; Vredenburg has expressed the opinion that the lowest Eocene horizons in the north trespass down into the uppermost Laki, a possibility with which Eames is in agreement. Evans divides the Jaintia series into a lower stage, the Sylhet Limestone, and an upper stage named after the Kapili river which traverses it, but states that the former may to some extent pass laterally into the carbonaceous alterations of the Kapili.

The Sylhet Limestone, a trade name for the rock so much quarried locally, is a stage made up chiefly of foraminiferal limestones with a total thickness ranging up to something less than 1,000 feet. Although the basal bed of the Sylhet Limestone sometimes rests with no visible discordance upon the Cretaceous, the latter is overlapped by the younger formation, and there is a palæontological gap between the two corresponding to the uppermost Cretaceous, Palæocene, and lowest Eocene. Within the stage itself small local unconformities and overlaps are characteristic. In the west the beds are thin and impure. The upper three limestones of the Thariaghat section belong in all probability to this stage ; the lowest of these shows sections of gastropods and tiny foraminifera, the middle is an Alveolina limestone, while the highest is built up of large and medium-sized nummulites. Eastwards the beds disappear beneath alluvial deposits but emerge again and swing sharply northwards under the scarp of Lumkharoh hill and form prominent

[287] Mem. 67, 35 (1931).
[288] Gen. Rep. Rec. 71, 85 (1936).

crags in the Litang valley; they are well exposed in the Kapili and many of its tributaries, where they include some shaly limestones alternating with the purer varieties, and a few impure ironstones. At the edge of the plateau at Sandai and Nongtalang the limestone forms cliffs, some of them 200 feet high, in which occur several large caves.[289] Omitting alluvial interruptions the Sylhet stage can be traced up into the Mikir hills, where it is composed of thick beds of limestones separated by thin shales and sandstone. In this section, below the lowest bed of limestone is a grit which has been locally quartzitised; in places it is underlain by coal which it is thought should be included in the Eocene sequence rather than the Cretaceous. The coal seam at Cherrapunji appears to be the same as that found four miles further north at Lairangao (Laitryngrew), and occurs in a sandstone belonging to the Sylhet limestones stage of the Eocene. Other coalfields belonging to this formation are those of Lakadong[290] and Mawsynram (Maosandram). In one section of the Mikir hills the Sylhet Limestone is overlapped by younger Tertiaries but reappears in the extreme east of the hills for a few miles in the vicinity of the Boro Neoria.

North of Thariaghat the Sylhet Limestone stage thins out with remarkable rapidity, from about 900 feet at Thariaghat to 80 feet at Cherrapunji 6 or 7 miles distant, and to 5 feet four miles further north, beyond which it soon disappears entirely. An outlier of the limestone occurs on the plateau northeast of Thariaghat.

Fossils in this stage include foraminifera said to be of Lower Kirthar age, and other forms such as *Thamnastraea* sp., *Litharaea* sp., *Isastraea*, and the gastropods, *Phasianella* sp., and *Turritella*. sp.

The Kopili stage, 1,000-1,500 feet thick, shows considerable lateral variation. In the Garo hills to the west, it includes clays, splintery shales and impure sandstones. On the borders of the Garo and the Khasi hills, near Nongkulang (Kulang) Evans records fossiliferous sandstones, light friable shales and red sandy clay, covering a large area. In Nongkulang hill some marine beds were described by Godwin-Austen as "unconformably overlying the Eocene and followed by the Nahan Sandstone"[291]; those beds, which have yielded fossils, including a new species of Clypeaster—*Cl. circularis* Spengl. and a *Eupatagus* related to the characteristic Nari species, *Eu. rostratus* d'Arch.[292]; this species is found also in the Eocene of western Sind and Cutch and belongs in all probability. Dr. Spengler has identified: *Clypeaster circularis* Spengl., *Eupatagus rostratus* d'Arch., *Tellina* sp., *Xenophora* sp., *Nerita* sp., *Natica* sp., *Solarium* sp., *Voluta* sp., *Conus* sp., *Cylichna* sp., and *Dentalium* sp.[293]

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[289] Gen. Rep. Rec. 21 (1900-1901).
[290] T. H. D. La Touche, Rec. 23, 14 (1890).
[291] H. B. Medlicott, Rec. 2, 10-11 (1869).
[292] E. Spengler, Centralbl. f. Min. Geol. u Pal. 623 (1915).
[293] Pal. Ind., New Ser., Vol. 8, No. 1, 68 (1923).

Further east the beds include thin coal seams. In the Khasimara valley, where the Kopili stage is about 500 feet thick, a few thin limestones are to be seen, but the bulk of the strata consist of shales and sandy shales, with bands of ironstone and flaggy sandstone. In the Kopili-Khorungma (Khrongma) area, where the thickness attains a maximum of 1,500 feet, Evans records the following section:

Alternating sandstones, thin fossiliferous sandstones, and shales.

A thick, hard sandstone, rather fine-grained, with shell fragments.

Shale with subordinate, thin-bedded carbonaceous sandstones.

Alternating grey shales and sandstones of various types.

A sandy fossiliferous mudstone.

Ferruginous sandstones, carbonaceous sandstones and grey shales.

The Kopili sediments on the whole, show less admixture between the arenaceous and argillaceous types than do the higher Tertiary beds of this area. The beds of the Kopili stage are comparatively soft and tend to occupy low ground.[294] The foraminifera of this stage are said to be of Middle Kirthar type.

At the western end of the Shillong plateau Eocene beds overlie the Cretaceous rocks which rest against the ancient Tura ridge. According to Pinfold, the Eocene sediments show a marked lithological change when traced eastwards to the Someswari river. In the latter section the beds consist of limestones with only subordinate sandstones and shales; further west, in the centre of the Garo hills, the limestones are much less conspicuous and are associated with a greater thickness of highly fossiliferous sandstones and shales, while at Damalgiri, the most westerly extremity of the outcrop, the beds, whose total thickness is not more than 150 feet, consist of calcareous mudstones with abundant nummulites and other fossils.[295] The Eocene here is overlain by soft sandstones similar lithologically to the Tipam series but containing Miocene fossils.

West of Tura the Sylhet Limestone and Kopili beds are represented by calcareous shales and impure sideritic limestones with characteristic Eocene fossils; these beds overlie the basal unfossiliferous sandstones with thin coal seams, resting on a floor of kaolinised gneiss or on a bed of kaolin derived thereform.

The following foraminifera and primitive plants have been recorded at various times from the Eocene of Assam.[296]

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[294] P. Evans. Trans. Min. & Geol. Inst. Ind., Vol. 27, 174-175 (1932)

[295] E. S. Pinfold, Rec. 50, 126 (1919).

[296] See H. C. Das Gupta, Journ. Deptt. Sci., Calcutta Univ. Press (1926).

FORAMINIFERA.

Nummulites scaber Lam. (equated by Vredenburg with *N. laevigatus* (Brug.), with which it is closely related),[297]

Nummulites obtusus Sow. (Equated by Vredenburg with *N. gizehensis* (Forks),

Nummulites perforatus (de Montf.) (megalospheric form of *N. obtusus*; under this ame are included species origially recorded as *N. lucasand)*,[298]

Nummulites beaumonti d'Arch. & H. (an Upper Kirthar form in Baluchistan ; found also in Italy (probably Lutetian) and in the Middle Eocene of Egypt),

Nummulites laevigatus (Brug) (including *N. lamarcki* d'Arch.),

Nummulites gizehensis Forks. (including *N. lyelli* d'Arch & H.), [299]

Nummulites ramondi Defr. (probably the young form of *N. atacicus*),

Assilina exponens (Sow.),

Assilina spira de Roissy,[300]

Discocyclina (Orthophragmina) dispansa (Sow.),

Discocyclina (Orthophragmina) radians d'Arch.,

Diatoms including *Eunotia, Navicula* and *Synedra,* and the algæ, *Lithothamnion gradis* Das Gupta, and *L. cherrapunjiensis* Das Gupta,

Alveolina sp.,

Quinqueloculina sp.,

Triloculina sp.,

Textularia sp.

GASTROPODA.

Gisortia gigantea Münst. (from Cherrapunji ; included by Vredenburg in *G. Gisortiensis* Valenc.,[301]

Gisortia silistrensis Vred. (Nummulitic limestone at Cherrapunji).[302]

The presence of *Nummulites beaumonti*[303] would seem to indicate an Upper Kirthar horizon. From a limestone at Lairagao and a rock like it at Cherrapunji. Dr. Stoliczka has identified,[304] the additional forms:

FORAMINIFERA.

Operculina canalifera d'Arch. (portions of the rock at Cherrapunji made up almost entirely of small specimens of this species).

ACTINOZOA.

Trochocyathus sp.,

Stylocœnia vicaryi Haime.

[297] W. L. F. Nuttall. Rec. 59, 136 (1926).

[298] W. L. F. Nuttall, Rec. 59, 124 (1926).

[299] See Jean Boussac, Mem. pour. servir. a l'explic. de la Carte. geol. det de la France. pp. 8-9 (1911).

[300] The identification of the characteristic Laki species, *Assilina granulosa* from Assam (found in an earthy limestone almost entirely made up of this foraminifer at Ryak on the Someswari River in the Garo district H. B. Medlicott Mem. VII, 167) is questioned by H. C. Das Gupta and Mr. Eames. The presence of *Nummulites gizehensis*, however, if rightly identified, is in favour of the conclusion that Laki horizons are present for this species has not been observed by Dr. Nuttall in any series other than the Laki in Western Sind (Rec. LIX, 127 (1926). The specimens from Thariaghat briefly described by Spendler are more likely to be Oligocene than Eocene (Pal. Ind., New Ser. VIII. Mem. 1, 67 (1923).

[301] Rec. 51, 128 (1920).

[302] E. Vredenburg. Pal. Ind., New Ser. Vol. 7, pt. 3, p. 76 (1927).

[303] Cinfirmed by Col. L. M. Davies.

[304] H. B. Medlicott, Mem. 7, 167 (1869).

ECHINOIDEA.

Echinolampas sphereoidalis d'Arch.

LAMELLIBRANCHIATA

Cardita sp. (small),
Ostraea sp.,
Pecten sp.,
Cardium salteri d'Arch. (found in the Laki of Sind).

GASTROPODA.

Ampullina (*Crommium*) *roualti* d'Arch. (d'Archiac's "*Natica roualti*"; a form found in the Ranikot of Sind and Kohat and in the Subathu of the Himalaya).
Cardium salteri d'Arch. (found in the Laki of Sind),
Keilostoma marginatum Lam.,
Ziziphinus sp.,
Cerithium hookeri d'Arch (small species, found in the Subathu of the Himalaya),
Turritella sp.,
Natica (casts of a larger species than *N. rouaulti*), *Terebellum* sp. (casts).

Both the Sylhet Limestone and the Kopili beds are shallow-water deposits.

The Disang series of Assam.—Under the heading of Eocene it is proposed to consider some beds of uncertain age found extensively developed in the hill ranges which separate Assam from north Burma and extend southwards through Manipur. Across the latter State both the eastern and western limits of the formation have been mapped and the width of outcrop shown as a little over 80 miles, but a considerable belt of newer rocks seems to have been included by Oldham in western Manipur, and later workers have tentatively included beds which are perhaps older than the Disangs originally described by Mallet further north.[305] Fifty or sixty miles is probably a closer estimate of the width of the main belt within which exposures of the Disang beds are confined. In any case it is impossible to make any estimate of their thickness until more is known of the tight isoclinal folding to which they have been subjected. Mr. R. D. Oldham correlated the beds with the Axials of the Arakan Yoma, the southerly tectonic equivalent of the Manipur hill ranges. Maclaren objected to such a view on the grounds that, unlike the Axials, the Disangs contain neither serpentine intrusions nor indurated cherts; he remarks that quartz veins are less characteristic in the Disangs.[306] Others, including the writer, consider that the bulk of the Disangs have more in common with the Negrais beds of the southern region, though less highly contorted. Hayden suggested that the series of parallel ranges between Assam and Burma may be made up of a great flysch formation in which representatives of both the Trias and the Cretaceous systems are present; he also expressed the opinion that in the Lushai hills at any rate, where a species of *Schizaster* had been discovered by La Touche at Lungleh, this flysch

[305] Mem. 12, 286 (1876).
[306] Rec. 31, 188 (1904).

might extend up even into the Tertiary.[307] That the latter suggestion is probable has been shown by P. Evans of the Burmah Oil Co. who recently found nummulites in what is considered to be a narrow extension of the Disang outcrop along the foot of the Barail ridge. It is quite probable that the Disangs will eventually be shown to be a more altered and practically unfossiliferous equivalent of the Laungshe Shales, which are a very thick formation, and perhaps in addition some portion of the Eocene.

The Disang outcrop covers much of eastern Manipur and occupies large areas in the Sadiya Frontier Tract and the Naga Hills district, where it is broken by faults. It has been followed northeastwards as far as the Pangsau Pass over the Patkoi range, and was recognised by Murray Stuart in the Hukawng valley of upper Burma. The alluvial plain of the Hukawng lies on a broad basin of Tipam Sandstones which, towards the north, rest unconformably upon slaty sandstones and shales, pierced by intrusions of serpentine and believed to correspond to the Disang series.[308] Near the boundary between Manipur State and the Upper Chindwin district of Burma the Disangs are succeeded to the east by the younger Tertiaries, except in one place where an irregular exposure of Cretaceous rocks is said to intervene.[309] The beds to the west of the broad Disang tract are also younger Tertiary sediments, but the boundary between the two formations, throughout much of its length, is a reversed fault. According to Mr. P. Evans, branching off from the main outcrop at Kohima is a long narrow arm-like extension of the Disangs, over 100 miles in length, continuing southwestwards and westwards along the foot of the Barail range of north Cachar past the railway station of Haflong. The northern and northwestern boundary of this narrow arm is a continuation of the reversed fault or thrust which forms the western limit of the main Disang tract to the north; on the northwest side of this great "boundary" fault the Disang series as such has not been recognised.

The greater part of the Disang country is mountainous. Between Kohima and the peak of Sarameti, for instance, ridge after ridge, rising commonly 3,000-4,000 feet above the intervening, steep, well-watered valleys, is crossed on the way eastwards; each ridge becomes more uniformly higher until the Sarameti range is reached which contains several peaks from 9,000 to 12,000 feet high, lightly snow-capped during the cold weather. Not unlikely the limit of the Disang outcrop will be proved to occur eight or nine miles this side of the Sarameti range. The watershed between the Bramhaputra and Chindwin valleys occurs far to the west of this range coinciding with the Kopamedza or Nummuh range, nearer the centre of the Disang outcrop. The tops of many of the ridges give rise to a peculiarly level sky-line, a good example being seen at Sakhaboma, a day's march

[307] H. H. Hayden, Rec. 40, 288 (1910).
[308] Gen. Rep. Rec. 54, 53 (1922).
[309] See map, Mem. 19, part. 4 (1883). No trace of the same Cretaceous bed-mapped as an outcrop 11 miles wide around Arral was found by the writer 30 miles or so to the north.

east of Kohima. The jungle is very dense in places and the undergrowth usually sufficient to prevent progress. Paths are scarce in the wilder parts and often impassable; there is scarcely any communication between neighbouring villages which are, as often as not, at war with one another.[310] Oaks and chestnuts abound; forests of pine-trees, usually accompanied by small, stemless date-palms, occur somewhat capriciously on both the higher and lower slopes. Here and there flourishes the tree rhododendron, and many kinds of ferns and orchids are to be seen everywhere; near villages are found bamboos of enormous size, much prized by the people. The dense jungle, such as that seen on Nummuh, produces a rich, black mould; near villages this is used for raising small crops of indigo employed for dyeing blankets. In more open places a red, ferruginous soil is forming.[311]

The series comprises a great monotonous thickness of splintery, grey shales interbedded with hard bands of fine-grained, flaggy sandstones which, at first only a few inches thick, increase in importance towards what is believed to be the top of the formation; the uppermost sandstones, including that named by Mallet the Naogaon Sandstone, according to the suggestion of Evans, should be included in the superjacent Barail series. In the type sections of the Disang river the lowest beds are made up almost entirely of dark grey shales which, in the unweathered condition, are more like mudstones, but become finely laminated when affected by the weather. Some of the shales show a slight concretionary structure, and occasionally distinct concretionary nodules are to be seen in these beds. A peculiar crinkled surface characterises the laminae of some of the shales. Ferruginous varieties are not uncommon; numerous ferruginous concretions, for instance, are to be seen in the shales between Mokokchang and Kohima which in this respect are very like certain members of the "Coal Measures" higher up in the stratigraphical scale. Iron pyrites is sometimes found in the shales, and carbonaceous matter is comparatively common. Between Mokokchang and

[310] In this extra-ordinary country, where truth is stranger and more sensational than any fiction, geological investigation can only be carried out under armed escort on the rare occasions when a punitive expedition finds its necessary to penetrate these unadministered tracts inhabited by wild, head-hunting tribes. In spite of the large belts of this jungle, exposures are better than they are in the low country nearer the Brahmaputra, but the complete absence of roads and the fact that the footpaths, when recognisable at all, zig-zag straight up to the top of each range and straight down again make progress easier for a monkey than for a human being. So accustomed to this are the strange inhabitants of this country, and so strongly developed are the climbing muscles of their legs, that many of them walk with bent knees like an ape. To follow them as they mount a slope of 45° or 50° with a pack on their back weighing 80 lbs. and singing as they go, takes one's breath away in a literal as well as metaphorical sense. Add to these obstacles the fact that on such expeditions to step off the narrow jungle footpath is often to count an unpleasant death from poisoned stakes of bamboo so hardened that they will pierce an ordinary leather boot, and it will be realised that the elucidation of the Disang flysch is likely to prove a slow and laboriable task.

[311] E. H. Pascoe, Rec. 42, 255-256 (1912).

Nangkan numerous indeterminable plant remains have been noted in the shales. A characteristic feature of the Disang shales is the number of "salt-licks" scattered over their outcrop (see p. 1588).

The sandstones, except those at the top which we are grouping provisionally with the Barails, are never very thick and in many cases appear to be little more than massive impure varieties of the shale; some of them like certain of the shales show a slight concretionary structure. There is a notable absence of limestone in the Disang series.

Towards the interior of the hills the Disangs show increasing metamorphism, the argillaceous beds becoming slaty and ultimately hard, glossy, dark blue slates weathering to a pale grey green. Further still east, in the vicinity of the serpentine intrusions but not necessarily for that reason, the argillaceous beds attain the degree of phyllites, frequently talcose or chloritic, green in colour and soapy to touch, while carbonaceous matter occurs in the form of graphite. In the Tuzu valley slate of excellent quality is available and is much used by the Nagas for roofing purposes. In the more metamorphosed area veins and lenticles of quartz, sometimes three or four feet across, traverse the slates; similar intrusions on a smaller scale are also seen in places among the unaltered shales. Hayden notes an increase in the metamorphism of the beds southwards from Mokokchang to Kohima, until in the immediate neighbourhood of the latter town some of the beds might almost be called schists.[312]

Beyond the Tuzu river and some 8 or 10 miles northwest of the peak of Sarameti (12,557 feet) a thick band of conglomerate was noted by the writer in two traverses made by a punitive expedition. The strike of the rocks is here N.E.-S.W. Along the southeastern side of its outcrop this conglomerate is in contact with a thick band of intrusive serpentine, and a thinner band of the same intrusive is seen close to in the shales on its northwestern side; in these shales, a little northwest of the thin serpentine band is a bed of green grit. In the conditions under which this interesting conglomerate was seen, it was impossible to explore its relationships, but it may well prove to be the base of the Disang series. On its southeast side the beds, which differ generally from the Disangs only in the greater degree of metamorphism they have experienced but which also include unaltered shales of ordinary Disang type, have already been mentioned under the provisional name of Makwari beds; like the Disangs they are traversed by quartz veins. The conglomerate, which sometimes passes into a coarse, pebbly sandstone, contains pebbles some of which have been derived from the serpentine; to the east of Chimi village, after which it has been provisionally named, it is of great thickness and occupies a lofty ridge well supplied with water.[313] The green, felspathic grit or sandstone, near the presumed base of the Disangs, is a thick massive bed, varying in composition but containing, besides angular grains of quartz and felspar, chlorite and serpentine and fragments of pyroxene and olivine.

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[312] Rec. 40, 285 (1910).

[313] E. H. Pascoe, Rec. 42, 261 (1912).

Such as it is, this evidence makes the base of the Disang series younger than the serpentine intrusion, to which a Cretaceous age has been provisionally assigned; the Disang series might, therefore, represent the lower Tertiary, perhaps transgressing downwards into the topmost Cretaceous. What appeared to be a very badly preserved cephalopod, at first thought to be an ammonite, was obtained by Hayden at Nangkam (Lungkam), but it is not certain whether it is truly of organic origin.[314] The pebble picked up by Noetling in the Hukawng valley and found to contain an ammonite, [315] is thought by Murray Stuart to have come from the Disang series, but this is also certain and in any case the pebble and its ammonite, if a constituent of a Disang conglomerate, may have been derived from an older formation.[316] No definitely recognisable and indigenous fossils have so far been found in the main belt of the Disang series.

With regard to the long, narrow, arm-like extension of the Disang outcrop along the base of the Barail ridge, Mr. Evans has obtained definite evidence of its Tertiary age in the presence of foraminifera referred preliminarily to Jaintia species;[317] on this evidence it is suggested that the stratigraphical position of the series corresponds closely with that of the Laungshe Shales of Burma, which are belived to straddle the Palaeocene and Eocene. The fossils were found in a loose block of sandy shales belonging to this outcrop, not far from Haflong, some 50 miles or so west of the edge of the main Disang exposure. This quasi inlier below the Barail ridge occupies low ground coinciding with the strike valleys of the upper Larang, the Kayang and the upper Jatinga.[318] West of the Kayang the great boundary fault has cut out all but the upper beds of the series, which are described as passing up into the Laisong stage of the Barail series.

Stuart has recognised the Disangs on the other side of the Patkoi range in the Hukawng valley of Burma. They comprise unfossiliferous, grey, slaty sandstones and slaty arenaceous shales, dipping at about 45° and apparently covered unconformably by Tipam sandstones, the slaty cleavage being at most invariably parallel to the Patkoi range. Disangs thus occur on each flank of the broad Patkoi syncline of Tipam beds. On the Burma side they are exposed along part of the valley of the Taron river and of its tributary the Loglai. One of the shales was observed to be carbonaceous and near it a few poorly preserved unidentifiable lamellibranchs were found.[319] Other characteristics are " salt licks " and intrusions of serpentine. The rocks are practically free from quartz veins but show signs of metamorphism near the Ta-ap serpentine intrusions, where they approach

[314] Rec. 40, 287-288 (1910); Hayden alludes to Cretaceous echinoids found by La Touche in the Lashai Hills south of Manipur, in beds apparently similar to the Disangs (Rec. 40, 288 (1910), but no record of this appears to be available).

[315] Rec. 26, 34 (1893).

[316] Rec. 54, 403 (1922).

[317] Gen. Rep. Rec. 69, 83 (1935).

[318] P. Evans. Trans. Min. & Geol. Inst. Ind., Vol. 27, 177 (1932).

[319] Rec. 54, 402 (1922).

mica schists. South of the Gedu river, the Disangs are again unconformably overlain by the Tipams.

The Disang shales are described as very like those of the Kopili stage, in which, however, shales do not bulk largely. It is suggested by Evans that the Disangs include a deeper-water facies of the Jaintias and perhaps lower horizons ; in the latter case they would represent the Ranikot and Laki stages as well as the Kirthar, and possibly the uppermost Cretaceous.

Pondicherry.—Belonging apparently to that arm of the sea which, it is surmised, covered portions of Assam during the Palaeocene period is a foraminiferal limestone recently found among the Cretaceous rocks of Pondicherry. This limestone, on examination by L. R. Rao and Y. Nagappa, has proved to contain Discocyclina and other nummulines.[320]

II. PALAEOCENE AND EOCENE OF BURMA

Distribution.—The main exposure of the Burma Tertiaries occupies the valley of the Irrawaddy and that of its chief tributary, the Chindwin, on the east side of Arakan Yoma. The system is also represented on the western side of the range, along the Arakan coast, and since these occurrences belong to the Assam province of gulf, the description thereof will form an apt sequel to the preceding paragraphs.

The Arakan Coast.—To the west of the Arakan range, limestone with nummulites has been noticed near Kyeintali (Keantali) on the coast of Sandoway, and there can be little doubt that Eocene beds extend along the coast for a considerable distance. The islands of Ramri and Cheduba consist of sandstones, and clays with occasional thin bands of conglomerate,[321] resembling those along the eastern flank of the Arakan Yoma, and probably a large proportion if not the whole of these rocks belong to the Eocene series. The sandstones are either moderately firm, or else highly calcareous forming a hard ringing stone, grey in colour but weathering brown ; their texture varies from a moderately fine, even-grained stone to a coarse rock containing small quartz pebbles, grains of mica, and pebbles of clay up to ½ inch across. The sandstones are frequently massive, especially where they form the tops of the loftier hill ranges ; occasionally they are carbonaceous. Soft blue clay like that found elsewhere in the Pegu series is sometimes seen. Some of the clays pass into shale, others are brittle, blue grey in colour, and are frequently jointed by a system of irregular curved planes which split the rock up into a vast number of small prismoidal pencils parallel to the strike of the beds ; these " needle shales " are the result of sharp folding. The shales are occasionally gypseous and contain small nodules of clay ironstone. Sometimes alternating bands of sandstone and shale, each from a few inches to a foot or more thick, are observable. The matrix

[320] " Current Science ", 8, 166-167 (April, 1939).

[321] E. H. Pascoe, Mem. 40, 181 (1912).

of the thin conglomerate bands is partly calcareous and partly ferruginous, enclosing pebbles of white quartz, clay, etc. Irregular stringers of lignite occur in both the shales and sandstones, while true coal of Tertiary type is found on Ramri, Cheduba and Cap Islands; the first mentioned of these seams range up to 6 feet. Whether the Pegu series is present at all in this region is doubtful; with the possible exception of local limestones on the eastern side of Ramri, which may be of Mesozoic age, there is no incentive to divide the rocks of the islands into more than one series.

Fossils are rare, but the identification of *Nummulites laevigatus*, a species characteristic of the Lower and Middle Kirthar, proves that some, if not all, of the beds are Eocene. Lydekker has described the palatal tooth of a large globe fish, *Diodon foleyi*, obtained from Ramri Island and differing apparently from the species now inhabiting the Indian Ocean. A precisely similar tooth was found by Wood-Mason at Port Blair, Andaman Islands, in a sandstone rock. From the Yenandaung oilfield of Ramri comes a large *Pyrula* (*Melongena*) and from some interior part of the island some univalves resembling *Turbo* and a species of *Turritella*.[322]

Oil and gas seepages abound in both Ramri and Cheduba, in the Boronga and other islands, and are frequent along the Arakan coast. For many years oil in small quantity has been obtained by drilling in Ramri Island but much exploratory work in this phenomenally unhealthy region, in the form of both geological reconnaisance and boring operations, have been unsuccessful in discovering any oil accumulations of importance.

The few exposures of rock show steep dips, and it is surmised that they represent a succession of denuded isoclinal folds, usually overturned towards the east; a feature of these folds is their apparent sinuosity. This multi-anticlinal hypothesis is supported by analogy with the Boronga Islands, in the most easterly of which three sharp anticlines have been deduced; this island is about ¾ mile across and the beds strike in the direction of Ramri Island.

Salses.—One of the most interesting features of this region is the emanation of hydrocarbon gas to form salses or "mud volcanoes". Some of these are small and of the ordinary quiet type, the mud, propelled by natural gas, welling up some part of a fissure and producing either a gassy pool or, if sufficiently viscous, building up a cone of varying steepness. In other cases, fragments of fractured country rock are thrown out as well as mud in paroxysmal outbursts, often with the accompaniment of flames caused by the ignition of the gas. In both Ramri and Cheduba are well known examples of the violent type of such vents, the periodical eruptions from which give rise to considerable local excitement. In these paroxysmal outbursts, the ignition of the gas is no doubt caused by a spark produced as a result of friction between rock fragments, and gives rise to spectacles of grandeur such as the celebrated Cheduba "volcano" occasionally exhibits. Flames and dense black smoke shoot to a great height,

[322] E. H. Pascoe, Mem. 40, 184 (1912).

accompanied by a rumbling noise, while a disturbance of a seismic nature is felt for miles around. Such a fierce eruption may last for nearly an hour. The ejected fragments of rock vary usually from ½-inch to about ½-cubic foot, the majority being four or five inches across, but some of the blocks on the Pagoda Hill of Cheduba exceed 4 cubic feet. The latter "volcano" is from 200 to 250 yards in diameter, covers about 20 acres and has a main crater measuring at times 40 feet across with subordinate craters in its immediate neighbourhood. Between the violent eruptions gas bubbles up at a furious rate through the mud of the main vent. Where the mud is viscid, the cones are very steep.

Besides gas and mud, a small quantity of petroleum is usually discharged from the vents. The gas consists mainly of marsh gas, probably mixed with small quantities of higher homologues of this and other hydrocarbon series. The mud is simply the clay or shale of the Tertiary rocks mixed with water containing salt in solution. In normal circumstances the mud in the vents is either of the same temperature as the air or a little higher. Both petroleum and gas are found in many localities amongst the Tertiary rocks of Extra-peninsular India and Burma. Not infrequently they issue with saline water in the form of a bubbling spring ; whether such a spring forms a "mud volcano" or not depends evidently on the nature of the beds traversed by the gas and oil on their way to the surface.

There are over a dozen vents in Ramri island, more than half that number in Cheduba, and a few in the other neighbouring islands. Near Kyaukphyu in Ramri, six occur in a line, within a distance of about a mile-and-a-half along the summit of a low, broad ridge. The majority of the Ramri mud volcanoes consist of mounds, composed on the surface of angular fragments of rock and having scattered over them a few small mud cones with craters at the top, varying in height from a few inches to eight or ten feet. When gas ceases to be emitted from a vent, the mud is rapidly washed away by rain and there remains a low mound composed of angular rock fragments which had been ejected with the mud ; the repetitions of such a process accounts for the formation of the mounds. The mounds in Ramri are from 50 to 100 yards across, with a height varying from 15 to 30 feet.

Gas and mud eruptions, often along the same line of strike, are frequent off the Arakan coast and sometimes give rise to transient islands, which appear and suddenly disappear within a few days or weeks, leaving behind a dangerous shoal.[323] They are also responsible for local earthquake shocks. In ancient accounts of by-gone disturbances it is not always easy to distinguish between true earthquake phenomena and phenomena attributable to the liberation of gas. It is highly probable that the two have often occurred simultaneously, and it is to be expected that the liberation of accumulated and concentrated volumes of gas might be prematurely brought about

[323] E. H. Pascoe, Mem. 40, 187, 213 (1912) ; J. Coggin Brown, Rec. 37, 26 ; (1908), Gen. Rep. Rec. 56, 22, 250 (1924).

by an earthquake. We should, therefore, rather expect to find a true earthquake in such areas accompanied by outbursts of gas and the pseudo-volcanic effects produced thereby. The converse, however, does not follow, and most of the eruptions in Ramri, Cheduba and elsewhere have been entirely unaccompanied by any truly volcanic or seismic characteristics. Very rarely fragments of burnt and reddened shale have been found, evidently calcined by the flaming gas, but the fact that the stones and even fragments of lignite, thrown out during eruptions are in nearly all cases entirely unchanged by heat, proves that the gas was not in a heated state previous to emission. An "earthquake" is frequently reported in the immediate vicinity of the gas eruption, but this is the result of a slight and purely local subsidence caused by the escape of the imprisoned gas, and has no far-reaching effect.[324]

The disturbance produced by these gas and mud eruption is excusably attributed by ordinary travellers to volcanic causes, but they are not of deep-seated origin and have nothing to do with true volcanic phenomena.

Salses, gas springs and mud volcanoes are known to occur in many other parts of the Extra-peninsular region. Some of these have already been described; others, such as the mud volcanoes of Minbu, will be mentioned in the sequel, since they occur in or are derived from younger rocks. No feature of this kind has been found within the boundaries of Peninsular India.

The Irrawaddy and Chindwin valleys.—Besides the main exposure of Tertiary rocks along the valleys of the Irrawaddy and Chindwin, numerous outliers occur beyond the confines of the central outcrop, especially to the east thereof. This broad geosyncline possesses an unusually full sequence of the Tertiaries from Thanetian to Pliocene, as the following table will show.[325]

Irrawadian series			Pliocene to Vindobonian.
Pegu series	Upper	Akauktaung stage	Vindobonian.
		Pyalo stage	Burdigalian.
	Middle	Kama stage	Aquitanian.
		Singu stage	Chattian.
	Lower	Padaung stage	Stampian.
		Shwezetaw stage	Lattorfian.
Eocene series.	Upper	Yaw stage	Priabonian.
		Pondaung stage	Auversian.
	Middle	Tabyin Clay	Lutetian.
		Tilin Sandstone	Lutetian.
	Lower	Upper Laungshe beds	Ypresian.
Palæocene and uppermost Cretaceous.		Lower Laungshe beds	Landenian. Montian. Danian.

[324] E. H. Pascoe. Rec. 60, 154 (1927).

[325] Mem. 72, 21 (1958).

(i) THE NORTHERN PART OF THE ARAKAN YOMA AND ITS CONTINUATION.

Mode of occurrence.—The Eocene in the districts of Minbu, Pakokku and Lower Chindwin, along the eastern flank of the Arakan Yoma and its northward continuation, has been the subject of detailed study by Dr. G. de P. Cotter.[326] In this region the Palaeocene as well as the Lower, Middle and Upper subdivisions of the Eocene are present in long N.-S. belts, occurring in a general way between the older Axial group to the west and the younger Pegu series on the east. Structurally, therefore, these beds form part of the eastern flank of the great anticlinorium of the Arakan Yoma. A continuous belt of these beds, locally concealed by alluvium and other younger deposits, has been traced from Cape Negrais in the south to the northern borders of the Lower Chindwin district, beyond which the country is largely unsurveyed. La Touche, however, records the presence of Nummulitic limestone in the northward continuation of the Pondaung range, between Kyaukpyauk and India in the western border of the Upper Chindwin district.[327] The Axial beds, whatever their age may be, form the core of the hills, and are succeeded to the east by the Laungshe Shales, except along a section from Tilin northwards through Gangaw, where a broad belt of Irrawadian beds (Maw Gravels) and a short attenuated strip of Cretaceous and Upper Eocene beds intervene.

PALÆOCENE AND LOWER EOCENE.

The Laungshe series.—The Laungshe, named after a village in southern Pakokku, is essentially a shale stage, with subordinate bands of sandstone and, at or near the base in most sections, inconstant conglomerates which die out or attenuate in certain areas. Conglomerates are not limited to the base of the formation, nor are they invariably found there ; they are typical of the lowest 2,000-4,000 feet of the Laungshe stage, in which they form a not always recognisable conglomeratic zone. This zone is characteristically displayed at Paung-gyi in the Ngape area of southern Minbu, and at Shwelegyin in southwest Pakokku. In the Ngape area, where the formation rests upon the Chin Shales, the conglomerates are accompanied by massive grits and sandstones ; the conglomerates at Shwelegyin have yielded small nummulites and specimens of *Discocylina,* from which it would appear that the conglomerate zone is probably of Palæocene age. As we have seen, however, there is a still lower zone of the Laungshe stage at Yeshin, where Palæocene beds pass down into the uppermost Cretaceous or Danian which, with its *Cardita beaumonti* fauna, has been included in the Laungshe stage as a basal zone or sub-stage.

[326] Mem. 72, pt. 1 (1938) ; The belt of Eocene shown on the 32-mile map immediately west of the Yoma crest in Sandoway appears to be a Cartographic error (see Cotter. Mem. 72, 24 (1938).

[327] Rec. 24, 98 (1891).

This continuity of deposition from topmost Cretaceous to Palæocene and Eocene is paralleled, as has been shown, in Sind. In some places the Laungshe conglomerate is made up of large boulders of crystalline limestone and other recognisable Axial rocks. West of Sidoktaya, in Minbu, and lying upon fine contorted shales belonging to the Axials, the basal Laungshe bed is a conglomerate composed of quartzite pebbles from the size of a sand grain up to an inch in diameter lying in a mosaic of quartz with strain polarisation. Of the subordinate bands of sandstone, intercalated among the shales, some are soft and fawn-coloured, others hard and gritty; limestone beds are occasionally seen. In the extreme northwest angle of the Minbu district Clegg has recorded outcrops of *Globigerina* limestone and *Lithothamnium* limestone, occurring apparently low down in the Laungshe Shale group and not far from the boundary of these beds with the Axial group; these limestones would appear to belong either to the Danian or the Montian.[328] In Thayetmyo, the conglomerates of the conglomerate zone are only locally developed, and the boundary between the Axials and Laungshes not well defined.

In the vicinity of Yeshin, a village near the western border of Pakokku, a fossil bed about 180 feet above that carrying *Cardita beaumonti* has yielded a typical Ranikot fauna:

GASTROPODA.[329]

Strepsidura indica Cossm. & Piss.,
Calyptrophorus indica Cossm. & Piss.,
Calyptrophorus hollandi Cossm. & Piss.
Lyria cossmanni Vred.,
Athleta eugeniae Vred.,
Athleta burtoni Vred.,
Athleta noetlingi Cossm. & Piss.,
Drillia jhirakensis Cossm. & Piss.,
? *Murex lyelli* d'Arch.,
Volutilithes cf. *cithara* Lam.,
Faunus vulcanicus (Schl.),
Potamides (Pyrazus) pyramidatus (Desh.).

FORAMINIFERA.

Discocyclina (Orthophragmina) cf. *trigonalis* cresp.

The first eight in the above list are Upper Ranikot species, while *Pyrazus pyramidatus* is a close relative of *P. octogonus* from the Hangu Shales (Lower Ranikot) of Kohat.[330]

Above the conglomeratic zone, the Upper Laungshes, probably between 9,000 and 12,000 feet thick, consist mainly of blue shale, sparsely fossiliferous, generally thinly laminated but often concretionary. Bands of blue clay are common. Thin layers of sandstone are found throughout, and in the higher horizons aggregate several hundreds of feet; they are, however, inconstant and frequently pass laterally into shales. Some of the sandstones contain small bands

[328] Mem. 72, 30 (1938).
[329] Gen. Rep. Rec. 56, 43 (1924).
[330] Pal. Ind., New Ser., Vol. 15, pt. 8, 150 (1930).

of conglomerate with a ferruginous matrix.[331] Here and there thin lenticular bands of limestone are seen. Thin layers of selenite are abundant throughout the Upper Laungshes, according to Captain F. W. Walker, who also found traces of fragmentary fossil plants. The general incompetency of the beds and the frequency of minor faults are responsible for the crumpling and local contortion. The higher Laungshe beds have yielded Laki fossils, including *Nummulites atacicus, Protocardium* sp., *Mytilus* sp., and near the top, *Operculina canalifera.* The upper Laungshes, therefore, appear to be the equivalent of the Laki of western India and the Libyan of north Africa.

MIDDLE EOCENE.

The Tilin sandstones.—The Middle Eocene is made up of the Tilin Sandstones below and the Tabyin Clays above, the two corresponding to the Lower and Middle Kirthar of western India. Between Tilin and Pauk, the Tilin sandstones form a well marked belt, at least 5,000 feet thick, between the Tabyin Clays and the subjacent Laungshe Shales, building up part of the Ponnya range. Northwards they thin out rapidly to a slender but constant band, averaging about 3.300 feet in thickness, and with a width of outcrop not much more than ½ mile. Southwards the band becomes less regular and is reduplicated in *échelon* fashion locally by two faults; towards Sidoktaya it tapers and at a point northeast of the town peters out. Further south it is impossible to locate any boundary between the Laungshe Shales below and the Tabyin Clay above.[332]

Although predominantly a sandstone stage, the Tilin includes intercalations of shale. In the constricted band north of Sobya the sandstones are described by Walker as fine-grained and compact, moderately thick-bedded, with numerous joint-planes and having the same greenish tinge as the younger Pondaung sandstones. In the Tilin-Pauk road section, the sandstones are described by Cotter as having a very fresh-water aspect and as containing abundant silicified wood. Here they vary in grain from coarse to fine and have in general a greenish-buff colour; red earth and gravel also occur. At one point in this road section the sandstones are felspathic. In the country south of Saw, the Tilins include a shaly middle zone separating two zones of sandstone, the latter comprising massive bluish varieties alternating with laminated fawn-coloured bands; in the lower zone Clegg records a fossil bed crowded with *Ampullina.* In north Minbu the shaly zone and upper sandstone zone appear to be replaced by alternating sandstones and shales. The shaly zone is well seen east of Laungshe; here the upper sandstone zone becomes coarse and conglomeratic. Conglomerates are also seen further to the south. The fossils, few of which have been specifically determined, comprise the following:

LAMELLIBRANCHIATA.

Arca cf. *bellovacina,*
Arca (*Noetia*) *pondaungensis* Cott.,

[331] G. de. P. Cotter, Mem. 72, 43 (1938).
[332] E. L. G. Clegg, Mem. 72, 162 (1938).

Glycimeris (*Pectunculus*) sp., *Glycimeris* (*Axinea*) cf. *puruensis* Mart.,
Ostraea sp.,
Anomia striata
Crassatella sp.,
Cardita sp.,
Meretrix sp.,
Tellina sp.,
Mactra sp.,
Corbula cf. *ficus* Brand.,
Corbula semitorta Bottg.

GASTROPODA.

Pleurotomaria sp.,
? *Nerita* sp.,
Velates sp.,
Natica sp.,
Ampullina sp.,
Turritella sp.,
Melania sp.,
Cerithium cf. *labiatum* Desh.,
Serraticerithium cf. *blainvillei* Desh.,
Volutospina sp.,
Mitra sp.,
Athleta sp.,
Oliva sp.,
Ancilla sp.,
Conus sp.,

The Tabyin Clay.—The clays and shales of the Tabyin stage, named after a village due west of Pauk, are described by Cotter as dark indigo blue in colour, clunchy, and full of carbonaceous markings and tiny brown specks of lignite. They often weather concentrically, and are distinguished from the Yaw Shales by their rather darker colour, and also by the thin bands of hard, compact sandstone which occur interstratified regularly throughout the formation. The sandstones are fine in grain, with occasional pebbly patches and layers ; some of them are ashy in character. In the Kyaw area, east of Gangaw, northern Pakokku, the beds are more sandy than they are farther south, and thin seams of coal are seen, reaching in some cases 18 inches in thickness ; in this part of the exposure also there are several gas pools and oil seepages, especially in the Ponnyadaung monocline. In the south, towards Sidoktaya, thin lenticles of limestone make their appearance in the stage. The beds of the Tabyin stage weather readily, and show considerable disturbance, contortion and irregularity due to the over-riding of the massive Pondaung Sandstones which succeed them stratigraphically. Neither the upper nor the lower boundaries are very clearly defined, the upper showing a gradual passage into the Pondaung beds. In the Kyaw area the estimated thickness is 4,000 feet, but further south it is thought to be nearer 5,000 feet.

Very few fossils have been found in these beds, but the presence of *Nummulites acutus* Sow., a form characteristic of the lower part of the Middle Kirthar, provides an important clue regarding the age of the stage ; the only others are *Arca* (*Noetia*) *pondaungensis* Cott., common in the beds above, and some poorly preserved lamellibranchs,

From the vicinity of Sidoktaya southwards, owing to the disappearance of the intervening Tilin Sandstone, the Laungshe and Tabyin clays are not readily distinguishable and have been mapped by Mr. Clegg as one group.[333] The beds of this group have yielded *Nummulites atacicus* and *Assilina granulosa,* and dip usually between 30° and 50° more or less regularly to the northeast; in southern Minbu and northern Thayetmyo there is considerable faulting and folding along their boundary with the Axial beds. The presence of *Nummulites acutus* Sow. in a fossil bed two or three miles northeast of Ngape proves that the Tabyin Clays are exposed in this part of Minbu; they contain calcareous lenticles showing cone-in-cone structure.[334]

UPPER EOCENE.

Mode of occurrence.—Unlike the somewhat sporadic occurrences in India, the examples of the Upper Eocene are well authenticated and cover considerable belts of country. The upper Eocene is found not only along the foothills of the Yoma and Chin Hills in normal sequence to the Middle subdivision, but the outcrops of both its two stages, at the boundary between the Pakokku and Lower Chindwin districts, spread eastwards and cover a wide area in the uplands northwest of Myaing. Throughout the greater part of the exposure, the beds have been thrown into synclinal and anticlinal structures of a major character.

Pondaung stage.—So far as the Pondaung stage is concerned, the eastward spread of the outcrop is accompanied by a change in facies. In the Yoma and Chin foothills, comprising the Nwamataung in north Minbu, the Yeyodaung and Dudawtaung on the borders of Minbu and Pakokku, and the Pondaung and Ponnyadaung of Pakokku and the Lower Chindwin districts, the Pondaung stage is of shallow-water type and contains marine horizons, while east of the Ponnyadaung the formation appears to be almost entirely a fresh-water one.

The Nwamataung, west of Salin, is occupied by a crushed, fold-faulted anticline, overfolded towards the west and with its western limb in places completely destroyed. The Yeyodaung-Dudawtaung range, which includes the sharp Ngahlaingdwin anticline, is also an asymmetric fold with steep dips in its attenuated western limb: in one place some 3,000 feet of beds appear to have been faulted out from this anticline. The Pondaung range is also a faulted anticline.[335] The structure of the Myaing area is that of a faulted, asymmetrical anticline like that of Gwegyo in Myingyan except that much older beds are exposed; both Pondaung and Yaw stages have been laid bare, and gas pools and oil seepages occur in the faulted crest. The most easterly occurrence of the Pondaung Sandstone is that seen in the Shinmadaung hills of Pakokku.

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[333] Mem. 72, 162 (1938).

[334] E. L. G. Clegg, Rec. 66, 251 (1932).

[335] The Geology of the Pondaung range has been described in detail by Dr. L. Dudley Stamp. (Trans. Min. Geol. Inst. Ind., Vol. 17, 161-180 (1922)).

The Pondaung beds show a rapid variation in thickness. Along the road between Pauk and Pasok the stage is about 3,500 feet, three or four miles further north it has increased to 5,500 feet, while still further in this direction it swells to nearly 8,000 feet. In the Mahudaung hills of the Lower Chindwin district, east of the Pondaung range, according to A. E. Day, 11,000 feet of the Pondaungs are exposed without the base being seen.[336] South of Saw the stage thins out rapidly to 1,500-2,000 feet.

In the more westerly exposures the Pondaung stage consists generally of coarse, often current-bedded. massive sandstones, greenish in fresh sections but weathering to a brown surface, with occasional bands of shale which become more and more frequent towards the base and thus form a passage into the Tabyin Clay below.[337] Passage beds, consisting of sandy limestones and shales at the base of the Pondaungs, are well seen at the southern end of the Pazawbya syncline near Sidoktaya. Strings and seams of coal are to be seen in the Pondaungs, and there are several outcrops of oilsand and seepages of oil and gas. West of Pauk, thin conglomerate bands form part of the succession, with abundant quartz pebbles, pebbles of sandstone, serpentine and mudstone: one band near the bas is comparatively constant. Fossil wood occurs throughout but tends to be carbonised in the lower and silicified in the upper horizons. To the west of Pauk the upper boundary with the Yaw Shales is sharply defined, and the same quick passage is seen further north. The top of the Pondaungs is frequently marked by an oil-bearing sandstone.[338]

Towards Sidoktaya in the south, the fawn-coloured and bluish, current-bedded sandstones become less massive, and fossil wood is confined more or less to the basal portion of the attenuated stage, which has here lost its prominence and become subordinate as a topographical feature. In this part of Minbu the Pondaung Sandstone forms the lowest exposed bed of the Ngahlaingdwin anticline. In the Ngape area of south Minbu the Pondaung stage is represented by a fossiliferous conglomerate carrying nummulites, and from 200 to 300 feet of sandstone.[339] East of Thayetmyo, where the stage is duplicated by strike faulting, the basal portion is marine while the higher portions contain fossil wood and are of fresh-water origin.

Fossil beds in the Pondaung stage are few and fragmentary, the only identifications being.

LAMELLIBRANCHIATA.

Ostraea sp.,
Arca (Noetia) pondaungensis Cott.,
Corbula daltoni Cott.,
Alectryonia newtoni Dalt.,

[336] E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chibber, Trans. Min. Geol. Inst. Ind., Vol. 21, 153 (1927).

[337] G. de P. Cotter. Mem. 72, 52 (1938).

[338] G. de P. Cotter. Rec. 44, 167 (1914).

[339] E. L. G. Clegg, Rec. 66, 251 (1932).

GASTROPODA.

Ampullina (a large species ranging up into the overlying Yaws).

Of the fresh-water facies found in the uplands northwest of Myaing, the basal beds are composed of very coarse conglomerates and boulder beds with pebbles and boulders of altered dolerite, gneiss and schist; in addition B. B. Gupta records pebbles and boulders of granite, diorite, quartz-augite rock, rhyolite, trachyte, porphyry, porphyrite, quartzite, and jaspideous rock, in the conglomerates of the Lower Pondaungs. The most important feature of this facies, however, is the abundant interstratification of the brown and buff sandstones with beds of highly coloured earths, sometimes with much ferruginous matter, cherry red, chocolate brown, bright buff, ashy-grey, cream-white, etc., which have yielded many interesting vertebrate remains. In places bands of selenite have been observed, and in one locality an ironstone bed near the top.

The Khodaung syncline 30 or 40 miles N.N.W. of Myaing belongs to the fresh-water facies of the Pondaungs, since it includes reddish purple clay bands with vertebrate remains; here the junction with the overlying Yaw beds is marked by a 6-inch laterite bed, evidently representing an old land surface.

The vertebrate fauna from the earthy beds, as determined by Drs. Pilgrim and Cotter exhibits an extra-ordinary predominance of anthracotheres which form about 95 per cent. of the total and constitute the most primitive types of this family known; with three exceptions—*Eotitanotherium, Metamynodon* and *Chasmotherium*—the general are all new[340]; the presence in the remaining 5 per cent. of titanotheres, tapiroids and the aquatic rhinoceros, *Metamynodon* (? *Paramynodon*), indicates, according to Pilgrim, a migration from North America.[341] The following identifications have been made:

TITANOTHERIIDAE.

Sivatitanops cotteri Pilg.,
Sivatitanops birmanicum Pilg. & Cott.,
Sivatitanops rugosidens Pilg.,
Eotitanotherium lahirii Pilg. (comparable with *E. osborni* Peterson from the Ludian of N. America),
Metatelmatherium (?) *browni* Colb.[342]

AMYNODONTIDAE.

Metamynodon cotteri Pilg. (Dr. W. D. Matthew prefers to assign these two species to a new genus, *Paramynodon*).[343]

TAPIRIDAE.

Indolophus guptai Pilg. (Nearest relatives of the genus are the Uinta *Isectolophus* and the European Eocene *Lophiodon*),
Chasmotherium (?) *birmanicum* Pilg. (Matthew assigns the genus to *Deperetella*).[344]

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[340] Rec. 47, 42-75 (1916); Pal. Ind., New Ser., Vol. 8, No. 3 (1925); Pal. Ind., Vol. 13 (1928).
[341] Proc. 12th Ind. Sci. Congr. 204 (1925).
[342] E. H. Colbert. Bull. Amer. Mus. Nat. Hist., 74, 304 (1938).
[343] Bull. Amer. Mus. Nat. Hist., 56, 513 (1929).
[344] E. H. Colbert, Bull. Amer. Mus. Nat. Hist., 74, 348 (1938).

ANTHRACOTHERIDAE.

Anthracohyus choeroides Pilg. & Cott.,
Anthracohyus choeroides Pilg. & Cott.,
Anthracothema rubricae Pilg. & Cott.,
Anthracothema palustre Pilg. & Cott.,
Anthracothema crassum Pilg. & Cott.,
Anthracokeryx birmanicus Pilg. & Cott..
Anthracokeryx ulnifer Pilg.,
Anthracokeryx bambusae Pilg.,
Anthracokeryx hospes Pilg.,
Anthracokeryx myaingensis Pilg.,
Anthracokeryx moriturus Pilg..
Anthracokeryx (?) *lahirii* Pilg.

FRAGULIDAE.

Indomeryx cotteri Pilg.,
Indomeryx arenae Pilg.

PRIMATES.

Pondaungia cotteri Pilg.
Amphipithecus mogaungensis Colb. (Probably an anthropoid ape).[345]

On external evidence the Pondaung stage falls between the Middle Kirthar of the Tabyin Clay and the Ludian (Nanggulan) of the superjacent Yaw beds. In confirmation of this, the Pondaung anthracotheriidae are more primitive than those of the Egyptian Lower Oligocene. As Dr. Cotter summarises, the Pondaung fauna is later than Middle Eocene and must be at least as old as Bartonian.

Close to the lower Chindwin river above Kani is an asymmetric anticlinal inlier of the Pondaung Sandstone stage, the deep dirty green colour of whose rocks contrasts with the yellowish Irrawadian sand-rock which surrounds the inlier. The Yaw stage and the whole of the Pegu series appear to be absent. The Pondaung rocks here consist predominantly of a uniform conglomerate, whose pebbles, ranging in size from a walnut to boulders one foot across, are well rounded and water-worn, and consist of igneous and metamorphic rocks. The rest of the sequence is made up of hard sandstone, shale and clay. Large pieces of fossil wood are common in the conglomerate and coarse sandstone, and carbonised impressions of leaves and twigs are seen on the shale. The faulted eastern boundary of the inlier presents a steep escarpment to the plain.[346] A little further west three other inliers have been noted, in all cases surrounded by Irrawadian rocks.

Yaw Stage.—The Yaw Shales accompany the Pondaung Sandstone and form an outcrop zig-zagging up the eastern flank of the Arakan Yoma and across Pakokku to Myaing. East of the Pondaung range the Yaws are greatly squeezed and contorted ; in north Pakokku step-faulting is common, and the Kyaw valley beds are characterised by frequent springs. The thickness of the stage varies usually between 1,500 and 2,000 feet. In north Pakokku it is estimated at

[345] Amer. Mus. Novit, 951 (1937).
[346] Gen. Rep. Rec. 62, 103-104 (1929).

1,800 feet, but the beds thin out considerably further northwards. In the Ngahlaingdwin anticline of north Minbu, 2,500 feet of beds are exposed, but in the more southerly parts of this district the beds are reduced to 300-400 feet and ultimately disappear as a result of overlap by the basal Pegus.

In the type section of the Yaw river, the stage forms a belt of soft, blue shales, lithologically resembling the Oligocene Padaung Clays of Minbu, with only occasional bands of limestone and calcareous sandstones. Here the Yaw beds, occurring as they do between two sandstone stages, occupy long valleys or areas of low relief. The whole stage is usually richly fossiliferous and in typical sections contains abundant nummulites. In north Pakokku the formation consists mostly of fine, bluish grey shale, weathering to a soft clay and containing thin bands of shelly conglomerate which stand out conspicuously from the weathered surface. Calcareous bands with cone-in-cone structure, and brownish bands of septarial matter are occasionally seen. Towards the base occur a few thin bands of sandstone, and seams of impure coal or carbonaceous shale which, though only a few inches thick, form a regular, persistent feature; also near the base in this area is a bed of fish remains. North west of Pauk the beds assume a shallow-water facies, nummulites are absent, fossils are broken and badly preserved, and layers of gypsum occur. A similar facies is seen immediately northwest of Myaing, where the Yaw shales are earthy and somewhat arenaceous, and contain fossil wood; the best seam of coal, under three feet thick, occurs here. In the anticline to the south of Myaing the Yaw beds, here subjacent and superjacent to fresh-water formations, are more marine in character, but fossils are rare. On the east side of the Maw valley, north of Tilin, a narrow strip of much crumpled Yaw shales, recognised by their fossil contents, lies strike-faulted against lithologically very similar Cretaceous beds on the east (basal Laungshe Shales) and is overlain along its western boundary by a broad belt of the Maw Gravels. In the Pakokku-Minbu border country, the Yaw stage is divisible into a Lower sub-stage, mainly of yellow sandstones containing silicified layers, with coal or carbonaceous shale at the top, and an upper sub-stage of alternating bands of sandstone and shale with fossils; foraminifera and corals abound in the upper sub-stage. A similar subdivision into two sub-stages is possible also in the Nagahlaingdwin anticline. Oil is found in the sandstones of this area, and the anticline has been tested by boring but without remunerative results.[347] South of the Ngahlaingdwin fold, the Yaw stage is described as made up of three main beds of shale separated by two bands of sandstone; the latter, which are fawn-coloured or green and frequently current-bedded, contain thin lenticles of coal. South of the Salin-Sidoktaya road the Yaw stage ceases to form a marked feature,[348] and no attempt has been made to map it as a separate unit

[347] C. Porro. Rec. 45, 249-268 (1915).

[348] Gen. Rep. Rec. 55, 35 (1923).

from the Pondaungs. In the upper Eocene of these parts, overlain by the steep, thickly forested scarp of the Shwezetaw Sandstone, the basal stage of the Pegu series, Yaw fossils as well as impure coal seams continue to be found.

In the Pazawbya area of Minbu the Yaws can be distinguished from the Pondaungs but are described by Clegg as passing down into the older stage through soft and shaly sandstones. In Pakokku the lower boundary of the Yaw stage is sharp, the change from the massive Pondaung sandstone to Yaw shale being sudden. Along the upper boundary, except to the northwest of Pauk where the lower Pegus consist of massive sandstones, the transition is more gradual, the shales of the older formation passing up with no apparent discordance into alternations of shale and sandstone and these in turn into more massive varieties of the Pegu sandstones. Of the shallow-water facies northwest of Myaing neither boundary is sharp. The upper limit of the Yaw stage is approximately marked by a bed characterised by *Velates perversus* (Gmel.), var. *orientalis* Vred.[349] The Yaw stage has been equated with the Nang-gulan series of Java.[350]

The fauna which has not yet been completely described, includes the following:[351]

FORAMINIFERA.

Nummulites yawensis Cott., (Restricted to the Yaw stage),
Discocyclina sella d'Arch., (megalospheric form; found also in Borneo),
Operculina cf. *canalifera* d'Arch.

LAMELLIBRANCHIATA.

Solen manensis Cott.,
Corbula (Bicorbula) subexarata, d'Arch., var. *lituus* (species common in the Laki and Kirthar of India),
Corbula paukensis Cott., (small species, very close to *C. watumurensis* from the Java Eocene),
Tapes birmanicus Cott. (widespread form),
Meretrix (Callista) yawensis Cott. (close to *M. bottgeri* Mart., from the Java Eocene).
Meretrix agrestis Cott. (perhaps identical with *Cytherea heberti* Desh. from Borneo),
Meretris cf. *sulcataria* Desh. (=*Venus subovalis* d'Arch.),
Blagraveia (?) *yethama* Cott. (related to the Borneo species, *Venus sulcifera, Venus paskoensis* Cott,
Tellina nanggulanensis Mart. (widespread form; found in the Upper Eocene of Java; related to forms in Borneo in beds of the same age),
Tellina (Colpopagia) tazuvensis Cott. (related to *Arcopagia colpoides* from the Paris Eocene, and ancestral to *T. grimesi* from the Burma Pegu,
Tellina salinensis Cott.,
Cardium kanleanum Cott., (one of the largest species known),
Cardium thetkegyinense Cott. (one of the commonest Yaw species; resembles *C. eduliforme* from the Borneo Eocene),
Cardium cotteri Cox (=*C. ambiguum* Sow.),

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349 E. Vredenburg, Rec. 53, 363-364 (1921).
350 G. de P. Cotter, Rec. 41, 221-238 (1911); E. Vredenburg, Rec. 51, 328 (1920).
351 G. de P. Cotter, Mem. 72, 68-71 (1938).

Pinna sp., (resembling *P. margaritacea* Lam.),
Ostraea minbuensis Cott.,
Chlamys cf. *multistriata* Desh.,
Leda silvestris Cott.

GASTROPODA.

Genota birmanica Vred., (closely related to *G. jogjacartensis* Mart. from the Upper Eocene of Java),
Genota garrowi Vred.,
Conus (*Lithoconus*) *gracilispira* *Bœttger* (also in the Upper Eocene of Borneo),
Gosavia humberti (d'Arch. & H.) (Very common throughout the Yaws; found in the Laki and Kirthar of Sind; =*Voluta birmanica* Dalt., *Gosavia birmanica* Pilg. & Cott. and *Aulica birmanica* Vred.),
Harpa (*Eocithara*) *birmanica* Vred. (closely related to *H. mutica* Lam. from the Middle Eocene of the Paris basin),
Marginella orientalis Vred. (also found in the Padaung Clay),
Athleta (*Neoathleta*) *rosalindae* Vred. (related to *Voluta cithara* Lam., from the Eocene of the Paris basin),
Athleta pernodosa (Dalt.),
Athleta (*Volutospina*) *augustae* Vred. (related to *V. elevata* Sow. from the Eocene of the Paris basin).
Athleta (*Volutospina*) *annandalei* Vred. (resembles *V. elevata*),
Athleta (*Volutocorbis*) *archiaci* Dalt. (=*Volutocorbis ickei* Mart. from the Upper Eocene of Java),
Volutilithes arakanensis Vred. (closely resembling a Javanese form doubtfully referred by Martin to *V. junghuhni*),
Scaphelta humilis Vred.,
Clavilithes cossmanni Vred. (closely related to *C. songoensis* Mart. from the Upper Eocene of Java).
Clavilithes songoensis Mart. (Upper Eocene of Java),
Semifusus heroni Vred. (closely related to *S. timorensis* Mart. from the Miocene of Timor and Java).
Lacinia indica Vred. (related to *L. sangiranensis* Mart.),
Velates perversus (Gmel.) (=*V. schideliana* Chemn.; found in India from the Ranikot to Kirthar; in Europe from Lower to Upper Eocene),
Cypraedia birmanica Vred. (perhaps an adult form of Martin's *C. conigera*),
Ampullina cf. *grossa* Desh. (found also in the Pondaung stage), also species of *Rimella*, *Hindsia*, *Natica* and *Sigaretus*.

In the Ngape area of south Minbu, the Yaw stage, characterised as usual by beds of impure coal and oil seepages, has yielded many of the typical fossils. At the top of the stage is a fossil band, known as the "Kyet-u-bok bed" which has yielded a fauna differing somewhat from that found in lower horizons of the formation, and has been traced southwards into the northern borders of the Thayetmyo district.[352]

FORAMINIFERA.

Discocyclina omphalus Fritsch (Upper Eocene of Borneo),
Discocyclina papyracea Boub., var. *javana* Verb. (found also in Thayetmyo),
Nummulites beaumonti (?) d'Arch. (identification needs confirmation; perhaps =*N. yawensis* Cott.).
Nummulites obesus d'Arch.,
Operculina cf. *canalifera* d'Arch.,
Gypsina globulus Reuss (ranges from Eocene to present day).

[352] Rec. 56, 39 (1924).

GASTROPODA.

Gosavia humberti d'Arch. (abundant throughout the Yaw stage; found also in the Laki and Kirthar),
Athleta (Volutospina) annandalei Vred.

LAMELLIBRANCHIATA.

Cardium thetkegyinense Cott., (abundant throughout the Yaws),
Cardium subfragile Bottg.,
Tellina (Colpopagia) tazuvensis Cott., and undetermined species of *Corbula, Chlamys, Triton, Chama, Natica, Conus, Turritella, Ampullina* and *Ficula*.

The thickness of the Pondaung and Yaw stages together reaches a maximum estimated at 5,000 feet in the latitude of Ngape but becomes reduced in a westerly direction to about 500 feet; this reduction is thought by Clegg to be due to marine transgression rather than to actual thinning out.[353]

The Yaw stage is the most important coal-bearing formation in Burma, though none of the seams is of any great value,[354] the coal being of inferior quality. Between Minbu and Ngape three of the seams aggregate some 9½ feet, the thickest being 4½ feet thick.

In the Upper Chindwin district many coal seams and isolated logs of silicified wood occur in strata which include one or two horizons characterised by gastropods *Melania*.[355] The beds are supposed to be an estuarine phase of the Yaw stage, and are exposed on the Myit-tha or Kale Creek, a few miles above its junction with the Chindwin at Kalewa. Twenty-five seams have been counted in the Maju valley, most of them two feet and under but rising in places to 12 feet in thickness. An aggregate quantity of 24 feet of coal is available in one area, and double that thickness in another. The coal or lignite is described as hard but of indifferent quality.[356] When undisturbed, its most striking feature is the high percentage of volatile matter. On distillation some of the lignites have yielded no less than 18.3 gallons of a crude oil not unlike that obtained by boring into the younger rocks of the important oilfields. Murray Stuart has suggested that the lignites are derived from logs and branches of *Dipterocarpus*, a genus which became abundant in the much younger Irrawadian series.[357]

(ii) THE SOUTHERN ARAKAN YOMA.

Thayetmyo.—That the Eocene belt extends through the district of Thayetmyo is proved by the recorded occurrence of *Discocyclina* ("*Orthophragmina*"), *Assilina granulosa*,[358] and *Nummulites atacicus*; the presence of the *Cardita beaumonti* beds in the Hlwa (Lhowa) stream makes it possible that the Laungshe Shales may also be present as part of the Eocene sequence of this part of the Yoma.

353 Rec. 66, 253 (1932).
354 K. A. K. Hallowes, Rec. 51, 34 (1921).
355 C. S. Fox, Mem. 57, 30-31 (1931).
356 V. Ball & R. R. Simpson. Mem. 41, 73 (1913).
357 Journ. Inst. Petr. Techn. 11, Oct. (1925) 475.
358 Rec. 41, 322 (1911)

Theobald's "Nummulitic group" must be regarded as largely Eocene but perhaps including also younger horizons. In the Hlwa stream, sixteen miles west and a little south of Thayetmyo town, upwards of 4,000 feet of hard sandstones, mostly grey in colour, and of blue, grey or yellow shales are exposed, but throughout this thickness of beds the only fossil remains detected are a few carbonaceous markings. On the Ma-tun stream, which joins the Hlwa from the north, and apparently at a somewhat higher horizon, there is a great thickness of massive shales, generally of a dark indigo colour but sometimes of a lighter blue. These shales cannot be much less than 3,000 feet in thickness, but they are almost as unfossiliferous as the Hlwa beds, the only organic remains found being some cycloid fish scales. Above these there is again a great thickness of sandstones and shales, mostly unfossiliferous but including a few nummulitiferous layers and at the top a discontinuous band of nummulitic limestone from 10 to 100 feet thick ; a few lenticular coal seams occur in the shales.[359] When present the nummulitic band appears to be the uppermost member of the group, but it frequently thins out or disappears, a result probably of erosion before the deposition of the succeeding group. Other limestone bands occur at lower horizons, generally associated with the more shaly bands, but are even more irregular than that at the top. Foraminifera in some places form reefs, and in others occur as isolated tests in some of the sandy rocks.[360] The total thickness of this Nummulitic formation must be considerable—probably not less than 10,000 feet—but no accurate estimate has yet been attempted. As defined by Theobald, however, it seems to have included somewhat higher horizons than the Eocene. Recently Clegg has found fossils belonging to some of the Eocene stages of Minbu and Pakokku but, south of latitude 20°, *i.e.*, south of the Ngape area of Minbu he has found it impossible to mark a boundary between even the Upper and Lower Eocene and the whole sequence from what are probably the Laungshe Shales to the Yaw stage has been mapped as one unit. The boundary between the Axials and the Eocene in this part of the Yoma is, wherever examined, marked by conglomerates and probably an unconformity.[361] In Myinmagyitaung and Thon-daung ("Lime Hill") a few miles S.S.W. of Thayetmyo town, the Yaw stage may be exposed, but this is uncertain.[362]

To the west of Thayetmyo the breadth of the Eocene outcrop from east to west is 17 miles but, a few miles to the south the width diminishes until, west of Prome, it is not more than 6 miles. The Eocene of this area is fossiliferous and is described by Stuart as lying with a considerable unconformity beneath the Sitsayan Shales one of the Pegu stages, by which it is overlapped [363] The base of the Eocene is here cut off by a fault from the Negrais beds.

[359] Gen. Rep. Rec. 56, 40 (1924).
[360] Gen. Rep. Rec. 71, 57 (1936).
[361] Gen. Rep. Rec. 56, 40 (1924).
[362] G. de P. Cotter, Rec. 54, 113 (1922).
[363] Rec. 38, 262 (1909).

The Eocene belt again expands in breadth near Akauktaung on the Irrawaddy above Myanaung, in the district of Henzada, but the beds are largely covered with gravel and other later deposits. Farther south, west of Myanaung and Henzada town, the axial portion of the Yoma is occupied by a broad belt of Negrais rocks, against the eastern flank of which are faulted interrupted outcrops of the Tertiaries consisting sometimes of the Sitsayan stage of the Pegus but more often of a sandstone series much concealed by post-Tertiary gravels, and believed to belong to the Eocene.[364] From the description, the latter might well be the Pondaung Sandstone stage, especially as the Sitsayan Shales in the Prome district were found to overlap from north to south successively older horizons of the Eocene below. Whatever it may be, this succession is almost entirely devoid of shales, consisting for the most part of massive sandstones, varying in colour from green to yellow, grey and blue, with occasional conglomerates; the only signs of organic life are carbonaceous markings which are common. Towards the base the beds are much indurated, like the Negrais rocks against which they are faulted.

Farther to the south, the only rocks seen west of the Irrawaddy plain are the altered Negrais beds, which are described below and which may possibly include Eocene horizons. Nummulitic beds reappear west of Bassein and continue thence, between Negrais beds on the west and the Irrawaddy alluvium on the east, to Cape Negrais (Pagoda Pt.), though much concealed by gravel. Northwards they remain hidden beneath alluvium for some 65 miles, reappearing west of Henzada town and continuing in this direction with only one small interruption west of Prome. Some coal-bearing sandstones in Henzada belong to this group and have been equated by Stuart with the Laki of western India.[365]

In the belt south of Prome, limestone with nummulites occasionally appears amongst the higher beds of the group. A peculiar, very fine, white or greenish, argillaceous sandstone, containing foraminifera, seen at Puriam Point east of the Bassein river as well as in Long Island, is also probably one of the uppermost Eocene beds; it is quarried to some extent and employed by the Burmese for the carving of images of Buddha.

(iii) THE NEGRAIS GROUP OF THE ARAKAN YOMA.

There has to be considered an outcrop of rocks of uncertain age, forming a prominent part of the Arakan Yoma and terminating southwards in Cape Negrais, after which it has been named. The very few organisms which have so far been detected in these rocks are mostly the indeterminable remains of plants and molluscs.

The Negrais rocks differ in no important lithological particulars from the Axial beds and, like these older strata, may include beds

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[364] Murray Stuart. Rec. 41, 249 (1911).
[365] Rec. 54, 403 (1922).

of widely different age. They consist principally of hardened and contorted sandstones and shales, intersected throughout by numerous small veins of quartz and carbonate of lime. Limestone is uncommon; where seen, it does not as a rule appear in regular stratified beds but in huge detached blocks embedded in the shales and sandstones, as if these softer beds had yielded without noticeable fracture to the pressure which dislocated the limestone. Conglomerates are also said to occur, sometimes passing into breccias, and reddish and pink clays are recorded by Theobald along the axis of the range. At Cape Negrais he notes the presence of crushed carbonaceous tree trunks and branches in the shales and sandstones.

The alteration of the beds is capricious and irregular. Frequently for a long distance the only alteration shown is a slight induration, after which they become cherty, slaty or almost schistose, and cut up by quartz veins. One not uncommon form of alteration is chloritisation, accompanied by intimate penetration by quartz veins. A more common form of alteration, seen along the coast north of Cape Negrais, is apparently due to the infiltration of silica in large quantities, the result being an abrupt change from sandstone into cherty masses. Irregular dyke-like intrusions of either serpentine or a decomposed steatitic rock are of infrequent occurrence.

The Negrais group must be of great thickness, but stratification is confused and, in the absence of any well defined horizon, no clear idea of the succession has been found possible. No definite boundary can be drawn between this group and the Palaeocene-Eocene belt. Both formations have the same easterly dip and away from the base of the hills the comparatively soft, unaltered, fossiliferous Palaeocene-Eocene rocks are in strong contrast to the hardened, crushed and in places almost schistose rocks of the Negrais group. The two formations, however, are never seen in mutual contact, there is no evidence that they are faulted against one another, and there appears to be a belt, often two or three miles wide, of rocks in an intermediate condition. Some of the Negrais beds appear to be a continuation of the Ma-i or Cretaceous beds.

The unsatisfactory evidence regarding the age of the Negrais rocks has been recently summarised by G. de P. Cotter,[366] whose opinion is that the rocks are older than the Eocene in spite of the *Vicarya* like shell found in them.[367] At Kywezin in Henzada certain coal seams, lying along the boundary of the Eocene (? Palæocene) and Negrais, were included by Murray Stuart in the basal Tertiaries. Later this coal was found by C. Beadon to yield fragments of an ammonite which L. F. Spath with much hesitation suggests may be one of those turricones—perhaps a species of *Bostrychoceras*—that are commonest at the top of the Campanian and especially the base of the Maestrichtian. Thus it is evident that the group is partly at least Upper Cretaceous but, as Cotter remarks, the impression

[366] Mem. 72, 22 (1938).
[367] Rec. 41, 250 (1912).

produced by what we know of this group is that it is a complex of several rock-groups not entirely Cretaceous and not entirely belonging to any other period. This observer considers that the distinction between the Negrais and Axial rocks is very doubtful and that, although the two may have been confused in places, there is some incentive for regarding the Axials as generally older than the Negrais. E. L. G. Clegg has little doubt that at the southern end of the Arakan range the rocks are probably all of Eocene or Cretaceous age,[368] and the conclusion expressed in the last edition of this Manual that the rocks under consideration possibly comprise representatives, slightly altered, of both Cretaceous and Nummulitic rocks, is probably not far from the truth.

The Andaman and Nicobar Islands.—The Eocene has been identified by Tipper in the Andaman Islands, which are but isolated portions of the Arakan Yoma, and probably also in the Nicobar group, a still further continuation of the same tectonic feature. The rocks of the Andamans are said to show great similarity to those of the Arakan Yoma, especially to the Negrais group. The structure of the Andamans is that of an anticline made up of Miocene resting unconformably upon Eocene rocks and thrust or overfolded towards the west. Since the Miocene beds show only slight disturbance, the main portion of this movement must have taken place previous to their deposition.

Covering most of the three chief islands of the Andaman group the Eocene shows a change of facies from a conglomeratic type in the north to a sandstone type in the south. In North Island the prevailing member is a coarse conglomerate, shales and sandstones being present only to a minor extent. The conglomerates grade from a very coarse type with large pebbles down to a sandstone; angular blocks are not wanting but most of the pebbles are rounded. Tipper calls attention to one readily distinguishable variety containing large rounded boulders of red and yellow jasper, derived from the old pre-Tertiary rocks of the island, and some of green serpentine.[369] The less coarse types are often made up of round pebbles of white quartz with a few smaller ones of jasper. A peculiar type seen at Port Cornwallis consists almost entirely of blocks of greenish jasper in a fine sandstone matrix; this type can be matched at Port Blair in South Island.

The sandstones, typical of South Island, are described as blue-grey, even-grained, either micaceous or calcareous, uniform in character over a wide area, and weathering in honey-comb fashion; those of Port Blair are said to be very like the Laki sandstones of Baluchistan. In South Island, intercalations of shale are frequent and conglomerates of white quartz pebbles in a sandy matrix are occasionally seen and become more frequent towards the north of the island.

The eastern half of Middle Andaman has been described in some detail by Gee and shows a transitional facies, containing both the

[368] Mem. 72, 178 (1938).

[369] Mem. 35, 198 (1911).

conglomerates of the north, the sandstones and clays of the south.[370] Some indication of the nature of the outcrop is given by the kind of vegetation it supports, the water-holding fertile soil of the serpentine tracts carrying a very dense evergreen type with thick undergrowths of cane and bamboo while the more porous soil of the sedimentaries, though well wooded, is characterised by forests consisting chiefly of the semi-deciduous *Pterocarpus*. Conglomerates with interbedded sandstones are seen in the northern parts of this island, especially in the vicinity of Cretaceous inlier, while clays and intercalated sandstones are more frequent in the south. Some of the conglomerates are quite coarse, with well rounded pebbles several inches in diameter; some of the harder quartzitic pebbles are somewhat angular. The pebbles are made up chiefly of white and yellow quartzite, with red jasper and grey quatzitic sandstone ; small pebbles of serpentine, andesite or vesicular basalt also occur. The matrix of the conglomerate is often arenaceous, but sometimes argillaceous, dull green in colour, and probably derived largely from the serpentines. The colour of the sandstones varies with the nature of the iron content, green types prevailing over brown and yellow varieties ; in some cases iron occurs in a concretionary form. In the eastern half of the island the sandstones are very massive and give rise to water-falls. Local intercalations of gypsum are mentioned by Gee. Some of the sandstones contain small fragments of soft green clay which Tipper suggests may represent much weathered serpentine. A prevailing dark or light green colour characterises the clays, though bluish varieties are not wanting ; they are often considerably indurated and shaly and occasionally contain calcareous concretions. Small pockets of friable coal are associated with both the clays and sandstones of the south.

According to Gee, the grains of the sandstones in Middle Island are usually very angular and include fragments of volcanic ash and felspar ; these ashy sandstones or grits grade into beds of volcanic tuff, usually of andesitic type. Outcrops of olivine basalt and vesicular augite-andesite are believed by Gee to be older than the local Eocene sediments but younger than the serpentine ; on the one hand pebbles of these lavas are found in the conglomerates. on the other hand, the lava outcrops themselves do not exhibit the marked alteration which characterises the older volcanic rocks associated with the serpentine series.

Carbonised plant remains, including dicotyledonous leaf impressions occur in many of the clays and in some of the sandstones. In South Island the only fossil found appears to be a fish tooth, *Diodon*, from Port Blair.[371] In North Island nummulites have been found in several localities, and identified as *Nummulites atacicus* Leym. and *Assilina granulosa* d'Arch. Although found in a coarse sandstone, they show no signs of attrition and do not appear to be derived ; their presence

[370] Rec. 59, 210-212 (1926).

[371] R. Lydekker, Rec. 13, 59 (1880).

is indicative of a Laki (Ypresian) age. In addition, Tipper records a poorly preserved *Turritella*, lamellibranch fragments, echinoid spines and a loose specimen of a *Nautilus* resembling an Eocene species from Sind. Foraminifera of the type *Assilina granulosa* are reported by Gee from Middle Andaman.

On the west coast of Rutland Island, sandstones with bands of shale or bedded mudstone form a N.E.-S.W. anticline and syncline and resemble the beds of Port Blair; the sandstones, which predominate, are blue-grey or yellow in colour and slightly micaceous.

At Jackson Creek in Little Andaman, fine, light green, slightly micaceous sandstones, form a prominent cliff on the northeast side of the bay, weathering in honey-comb fashion; lithologically they resemble some of the Port Blair types though on the whole finer in grain. Argillaceous varieties are interbedded. One of the sandstones has yielded an imperfect specimen of a thin-shelled *Pecten*.

In the Nicobar Islands, the Eocene of the Andamans is probably represented by the so-called "Nicobar Sandstone" or "Brown coal formation", though no fossils have been found to substantiate the correlation. The sandstones are lithologically similar to those of the Andamans and like the latter have been more severely folded than the clays of the later formation which is assigned to the Miocene. Carbonised leaf impressions and inclusions of fossil wood carbonised to coal have been noted. On Katchal there are conglomerates of Andaman type as well as small exposures of quartzites. Gee records that the rocks of Pulo Milo, and Kondul islands consist largely of sandstones, lithologically comparable with those of Rutland Island and parts of the main Andaman group. On the east of Pulo Milo they are steeply-dipping, grey, micaceous sandstones with intercalations of shale. Among the sandstone and shales of Kondul are thin lignite bands. Similar sandstones and shales are exposed in the extreme south of Great Nicobar, along the eastern shores of Galatea Bay; these also contain traces of carbonaceous material and dip steeply to the east. Further north, along the coast, cliffs of light green clays and argillaceous sandstone crop out.

In addition to the beds already described, several small outcrops of cream and grey limestone occur in the stream-beds of the northern part of Middle Andaman. Their relationship to the neighbouring arenaceous sediments is obscured by sandy alluvium. Sections show the rock to be composed largely of small somewhat globose nummulites and to contain also fragments of the alga, *Lithothamnium*, of the types *L. suganum* Rothpl. and L. *nummuliticum*, specimens of *Nodosaria* and *Globigerina* and moderately abundant echinoid spines. A post-Eocene age has been suggested for the beds, but the nummulites strongly suggest the Ranikot form, *Nummlites planulatus* Lam., and *Lithothamnium* and *Globigerina* limestones have been found by Clegg in the extreme northwest corner of Minbu, south of Kanpetlet, in the lowest horizons of the Laungshe Shales, not far from the boundary with the Axial group.

Hukawng Valley.—The well known Burmese Amber Mines are situated in the Hukawng valley, some three miles southwest of the village of Shingban. Here the eastern flank of the Maing-kwan hills is formed of rocks believed by Murry Stuart to belong to the base of the Tipam series. Underlying them on the west is the blue clay in which the amber is found in irregular lumps.[372] The amber is obtained from pits, ranging up to about 45 feet in depth, in a dozen different localities. [373] Amongst the debris around one of the pits a rock fragment has yielded *Nummulites biarritzensis,* a form which Nuttall believes to be the equivalent either of *N. atacicus* or *N. stamineus,* from which it is deduced that the beds beneath the Tipams are of Eocene (Kirthar or Laki) age. The insects found in the amber, according to F. A. Bather, also indicate an Eocene —possibly " Lower Eocene " age[374].

From neighbouring sections Chhibber describes the Eocene of this region as consisting of very finely bedded, dark blue shales, and sandstones, with a few layers of limestone and conglomerate ; in Kawt-ta Bum the beds are interbedded with volcanic breccia and fine-grained tuff. The sandstones, which are subordinate to the shales, are sometimes finely laminated and contain shaly concretions. Both the sandstones and shales are characterised by carbonaceous impressions or thin seams of coal, the latter occasionally containing small embedded fragments of amber. Nummulites are observable in the limestone. The beds are said to be folded up in tight anticlines and synclines[375] From analogy with an insect-containing amber of Pleistocene age, Murray Stuart has suggested that the Hukawng valley amber may have been the production of bees and derived perhaps from the oil and resin of *Dipterocarpus.*[376] The amber, known as burmite, differs from the normal succinite in its darker colour, slightly greater hardness, and a fluorescence which has been described as giving the mineral the appearance of solidified kerosene oil ; [377] unlike succinite it contains no succinic acid radical. In small pieces a similar fossil resin is reported from Mantha on the Irrawaddy in Shwebo but from beds which belong probably either to the Irrawadian (Pliocene) or the Pegu (Oligocene-Miocene) series ; it occurs in insufficient quantity for commercial purposes in a hard coaly clay underlying a coal seam.[378]

A little over 50 miles N.N.E. of the Amber Mines, some four seams of friable coal are reported as occurring in sandstones, shales and nummulite-bearing limestone, situated on the left bank of the Hkawngchit Hka and believed to be of Eocene age.[379]

[372] Rec. 54, 16, 404 (1922).
[373] Gen. Rep. Rec. 65, 33 (1931).
[374] Gen. Rep. Rec. 54, 16 (1922).
[375] Gen. Rep. Rec. 65, 78-79 (1931).
[376] Journ. Inst. Petrol. Techn., Vol. 11, 479 (1925).
[377] Ann. Rep. Rec. 26, 6 (1893) ; F. Noetling Rec. 26, 31-40 (1893) ; O. Helm. Rec. 26, 61-64 (1893).
[378] F. Noetling. Rec. 26, 39 (1893).
[379] Gen. Rep. Rec. 65, 37 (1931).

III. GEOGRAPHICAL RELATIONSHIPS.

In north Africa, where there is no sharp stratigraphical break between the two formations, not a single species survives from the Cretaceous fauna into the Palaeocene, and the same statement might be made with respect to western India if the word, variety, be substituted for species. Many of the Palaeocene fossils, especially the echinoids, show strong Cretaceous affinities, but the appearance of nummulites and operculines, as in other parts of the world, is sudden and abrupt. This has led to the conclusion that the time interval between the Cretaceous and the known Lower Palaeocene in the Indo-Pacific region "was a long one, sufficiently long at any rate to permit of the development of *Nummulites, Alveolina* and the other Tertiary types from Cretaceous ancestors", and that "this development must have taken place in the Indian Ocean, during a period when no known portion of the present land was submerged".[359] The acceptance of such an interval would indeed help to explain some of the contradictions in the evidence regarding the age of the Deccan Trap and its organic remains. if we imagine this volcanic episode to have coincided partly with this gap in the stratigraphical sequence. In weighing such a possibility, however, it must be remembered that the Tertiary Nummulinidae have ancestors in the Mesozoic and even in the Carboniferous Limestone. The abrupt way these forms have of appearing in the geological scale, must be partly due to their extreme susceptibility to obliteration by percolating water, especiallv in the case of the more minute species. A gravel of nummulites is an ideal medium for the process of chemical solution and the number of individuals which have survived such disintegration must be small in the extreme when compared with the number which have contributed to the formation of mountain ranges of massive and structureless limestone. Furthermore, the Palaeocene is one of the most restricted formations known and in the majority of countries is unrepresented.

In western India, in any case, the uppermost Cretaceous fauna is separated from that of the lowest marine Palaeocene or Landenian by some 1,500 feet of fresh-water sediments and one or two beds of trap. Even if it be inferred that the highest Cretaceous beds of this region the *Cardita beaumonti* beds—reach up only into the basal part of the Danian, we have some 1,500 feet of river silts with their basal oyster bed to represent the Upper Danian and Thanetian, and no long time interval is unrepresented unless we imagine it to be an unknown period between the Danian and Thanetian.

The Ranikot deposits of western India were accumulated in an angular gulf with the angle located somewhere north of the Punjab, the upper arm stretching thence eastwards to the vicinity of Lhasa, the lower arm southwards through Baluchistan, Sind and Cutch. This gulf debouched into the main sea which at that time covered the Arabian Sea and Indian Ocean, and extended up into the Medi-

[359] Bull. Geol. Soc. China, Vol. 6, 163 (1927).

terranean across Somaliland, Libya and the Red Sea area. That it was in this way continuous with the Atlantic and, by way of the English Channel, with the North Sea basin, is proved by the presence in the last mentioned area of southern types, especially that of the peculiar southern gastropod, *Velates*. Resemblances between the Palaeocene of Europe and that of India are, however, not close, and the two regions belong to two more or less different life provinces.

Some distance west of the Sind-Tibetan gulf, a short embayment from the sea projected north-westwards as for as the site of the Oman peninsula now at the head of the Persian Gulf. The Palaeocene deposits of Burma, if we assume the Disang beds to be the approximate equivalents of the Laungshe Shales, belong to a wide gulf extending northwards from the sea which then covered the Indian Ocean. This gulf stopped short in Upper Burma, just as the longer gulf over western India and Tibet stopped short near Lhasa. There was free marine communication between the two gulfs round the southern end of Ceylon, and with the Pacific region round the large blunt promontory of Cathaysia. In spite of this, the *Dictyoconoides* of western India does not seem to have reached the Burma and East Indies area.

If we accept the theory that the Indian peninsula drifted north-eastwards from more southerly latitudes to its present position, we must suppose, as would be natural that the northeastern corner of the moving landmass would be the first to impinge against the Angara continent, and that collision with the latter took place initially somewhere to the southeast of Lhasa. On this hypothesis the sharp pointed corner of the invading landmass would seem to have pushed its way well up into the re-entrant which at that time existed between the Tibetan and Cathaysian coasts, leaving a large angular gulf between itself and Angaraland to the north and north-west, and another wide N.-S. gulf between itself and Cathaysia to the east. The latter gulf, at any rate from Eocene times onward, seems to have been divided by a long narrow spit of land projecting southwards and occupying the site of the Arakan Yoma.

Between the Ranikot and Laki in western India there is a faunistic break not much smaller in magnitude than that below the Ranikot. Several groups of invertebrates show marked changes. Among the mollusca only 3 (possibly 5) species of gastropods and only 3 (possibly 4) species of lamellibranchs are common to the two stages, though, as L. R. Cox points out, this is partly due to a change of facies, the Upper Ranikot being mainly arenaceous while the fossiliferous portion of the Laki is calcareous.[381] This change, on the other hand, was accompanied by a closer relationship with Europe, many species being common to the two regions.

The Laki period was characterised by marine encroachment and a widening of the Ranikot gulfs, the more westerly of which, however, seems to have been affected by some obstruction in the latitude of

[381] Trans. Roy. Soc. Edin., Vol. 57, 32 (1934).

Waziristan. In Sind and Baluchistan the Laki is for the most part an *Alveolina* limestone separated from the Ranikot below by an erosional unconformity marked by a lateritic deposit. This unconformity varies in size from place to place and coincides with a northward overlap, the Laki lying upon older and older horizons of the Ranikot until in North Sind it rests directly upon the Lower subdivision of this stage. Further north the Ranikot disappears completely for a space but is found again in Kohat and the Salt Range ; as we shall see, the Laki also disappears in Baluchistan owing to a later overlap. Such behaviour of the beds is best explained by the deduction that a broad bar of silt formed across the lower end of the gulf in what are now the northern parts of Baluchistan. A barrier of some kind has also been deduced by Mme. de Cizancourt between Afghanistan and Kohat, for both the Laki and Kirthar faunas of the former are almost purely European in character and show remarkably little affinity with those of India.[382] A similar barrier seems to have obstructed intercommunication between Egypt, Palestine and Syria on the one hand and Somaliland on the other, for the Lower Eocene of the latter country has more in common with that of India than it has with the corresponding assemblages in Egypt and Asia Minor. Such obstructions as those just mentioned are examples of a localised and temporary recession of the sea which affected large areas and afforded facilities for the migration of land animals. Professor Morely Davies draws attention particularly to the retreat of the sea from eastern Russia towards the end of the Palaeocene and during the early Eocene, the result being the provision of a gangway for such migrants from Asia to Europe. Some of the Lower Eocene mammals of Europe, including the primitive hyracotherines, are plainly immigrants from America, presumably by way of Asia.[383] The formation of shifting land barriers seems to have been an early accompaniment of the Himalayan disturbance.

During the Eocene period the eastern gulf, covering the greater part of the Burmese area as well as the eastern margin of Assam, Manipur and the eastern fringes of Bengal, became split longitudinally into two separate gulfs at first by an archipelago of islands but eventually by a long ridge of land over what are now the Arakan Yoma and its northward and southward continuation. On the other side of the narrow Arakan Yoma ridge which projected southwards from the Angara land-mass, the Bay of Bengal, towards the end of the Laki period, reached as far as the southern margin of the Shillong Plateau and ended here in a steep shore which has been preserved till the present day.

Between the molluscan fauna of the Laki and Kirthar there is no pronounced distinction ; Cox finds 8 gastropods and 17 (possibly 20) lamellibranchs common to the two subdivisions and remarks that

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[382] de Cizancourt and L. R. Cox. Mem. Soc. Geol. France., N. S., 17, fasc. 1, Mem. 39 (1938).

[383] See A. Morley Davies "Tertiary Faunas", Vol. 2, p. 99 (1934).

further collections would probably increase these numbers.[384] There is still closer relationship with the Mediterranean fauna, especially with that of Somaliland, the Eocene of which country from base to summit shows a particularly well marked affinity with that of western India. The Kirthar of Burma forms a connecting link between that of the Indian Archipelago and the Philippines on the one hand, and western India and Europe on the other.[385] The earlier part of the Kirthar (Middle Eocene) in Java, Borneo, the Moluccas and New Guinea, with *Nummulites acutus, Discocylina javana* and many other discocyclines, shows unmistakable resemblances to the corresponding beds in western India.[386] The Mogattam (middle Eocene) of Egypt is especially characterised by the Kirthar nummulites *Orbitolites complanatus* and *Nummulites atacicus. Nummulites gizehensis* is known from Algeria eastwards to Verona, Egypt, the Dardanelles, Mesopotomia, America, India and Java. The Middle Kirthar nummulite, *Nummulites laevigatus* is a characteristic form in the countries bordering the Atlantic.

In Kirthar times certain geographical modifications took place. The Burma gulf persisted, and the adjoining bay continued to cover the southern fringe of the Shillong plateau but may have extended northeastwards as far as the Barail ridge. The upper portion of the large western gulf, along the northern flank of the Himalaya, receded from southern Tibet, but at the same time a smaller and shallower branch of the gulf made its way along the southern foot of the Himalayan range, reaching at least as far as Naini Tal. At its angle, according to Grabau, this west Indian gulf became confluent northwestwards with the south Russian sea with its boreal fauna. The lower branch of the west Indian gulf suffered in a general way continual subsidence, and the maximum known thickness of the Kirthar sediments, 9,000 feet, mostly of cherty limestone, is probably an underestimate. The bar across the inlet seems to have persisted and to have grown in size until the beginning of the Kirthar period. In the rare cases where the sequence is complete, the Lower Kirthar succeeds the Laki conformably; in most parts of Sind, however, the Middle Kirthar rests directly upon the Laki limestone, while in Baluchistan the Laki disappears as well as the Ranikot and the Kirthar in most cases rests upon the uppermost Cretaceous beds. The precise correlation of the Dunghan-Ghazij-Spintangi succession of northern Baluchistan and the Sulaiman area with either the Laki-Kirthar sequence of Sind or the corresponding sequence in Kohat and the Punjab is not yet completely known. The early Eocene small bay covering the 'Oman area advanced northwestwards', invading the Persian Gulf, a large portion of western Persia and a part of Mesopotamia. The Cathaysian peninsula shrank as a result of the marine invasion of Java and some of the smaller islands of the neighbourhood.

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[384] Trans. Roy. Soc. Edn., Vol. 57, 32 (1934).
[385] E. Vredenburg, Rec. 51, 243 (1920).
[386] W. L. F. Nuttall. Rec. 59, 123 (1926).

In general the Middle Eocene was characterised by a marine transgression, a differentiation of mammalian faunas and a tendency towards the unification of marine faunas; as an instance of the latter Professor Morley Davies notes the extraordinary ubiquity of *Velates perversus*, an unmistakable gastropod which has been recorded in the Bonin (Arzobispo) Islands of the Northwest Pacific, Burma, Sind, Persia, Armenia, Arabia, Egypt, Somaliland, Madagascar, the Sudan, Hungary, Dalmatia, Macedonia, North Italy, Bavaria, Switzerland, the Paris Basin, Spain, Jamaica and possibly California.

In Burma the Middle Eocene has yielded a restricted marine fauna and in Java and other parts of the East Indies is absent altogether. In these three countries it is the Upper Eocene which has yielded important marine faunas, which show no close relationship to the faunas of the Tethys. *Nummulites djokjokartae* from the Nang-gulan formation of Java is related to the Burmese *N. yawensis* and to the Kirthar forms, *N. acutus* and *N. laevigatus*.

CHAPTER XXX.

TERTIARY (CONTINUED)—THE OLIGOCENE OF INDIA

Sind and Baluchistan.—The Nari series of Sind and the adjacent parts of Baluchistan; The Kojak Shales; The Nari of northern Baluchistan; Fauna of the Nari. **Cutch. The Sulaiman Range. Assam:** The Barail series of Lower Assam; The equivalents of the Barail series in Upper Assam; The Naogaon Sandstone; The Coal Measures; The coalfields of Upper Assam; The Assam oilfields; Summary of relationships between north and south Assam.

SIND AND BALUCHISTAN.

The Nari series of Sind and the adjacent parts of Baluchistan.—The Tertiary series which follows the Kirthar Limestone of Middle Eocene age is superbly developed in the frontier hills of upper Sind. whose crest is composed of the limestone so named. It is known as the Nari series, corresponding to part of the European Oligocene, and derives its name from the Nari Nai, a stream whose upper course lies almost entirely among the beds named after it.[1] Further to the west in Baluchistan, from Gidar and Nal down to the northern edge of the Las Bela plain, the limestone ranges which form the western margin of the calcareous as distinguished from the flysch region also consist of an enormous thickness of these massive Nari beds.[2]

Whilst the Kirthar represents the European Lutetian, the Lower Nari corresponds closely with the Stampian. There is thus a gap between the two Indian stages, represented in Europe by the basal Oligocene stage—the Sannoisian—as well as the two uppermost Eocene stages, the Bartonian and the Priabonian (Ludian). In the Mula Pass of Baluchistan, this gap may be partially bridged by some beds at the top of the Kirthar above the zone of *Nummulites complanatus* and doubtfully referred to the Bartonian, as well as by some beds at the base of the Nari which are perhaps a local development of a portion of the Sannoisian; the latter, clearly of Oligocene age, consist of hard limestone with the echinoid, *Clypeaster apertus*, reticulate nummulites including *Nummulites intermedius* and a doubtful *N. contortus*, but with none of the lepidocyclines so characteristic of the immediately overlying beds in which they make their first appearance.[3] Even in the Mula Pass however, there is no complete passage from the Eocene to the Oligocene. Elsewhere, the Bartonian, Priabonian and the lowest portion of the European Oligocene appear to be absent.

The Nari series has been subdivided into Lower and Upper stages, the former an entirely marine formation, the latter largely marine

[1] W. T. Blanford, Mem. 17, 49 (1879).

[2] E. Vredenburg, Rec. 38, 195 (1909).

[3] E. Vredenburg, Rec. 34, pp. 89, 90, 173-174 (1906).

but partly fluviatile. The Lower Nari, with a maximum thickness of about 1,500 feet is much more fossiliferous than the Upper, which attains a maximum of 5,000-6,000 feet on the eastern flank of the Kirthar range, and is in places almost devoid of fossils. In parts of Baluchistan the Nari has a flysch facies and constitutes the lower part of what is known as the Kojak Shales ; such a facies occurs in corresponding beds further west, across the Persian frontier.

In their typical form the Nari beds extend throughout the eastern flank of the Kirthar range, and occupy a belt varying in width from one or two miles to as much as ten miles in breadth, between the underlying Kirthar and the overlying Gaj beds. The Lower Nari shows a biological break with the Kirthar but throughout Sind no angular discordance therewith. In Sind and Baluchistan, except in the Spintangi section, the Upper Kirthar, as we have already seen is invariably missing, various levels of the Nari or Miocene Gaj resting indifferently upon lower horizons of the Kirthar or upon some member of the Laki[4]. From the neighbourhood of Sehwan to Jhirak, the Pliocene Manchhar beds rest with more or less discordance on the Laki Limestone, a very faint and imperfect pebbly representative of the Gaj group occasionally intervening. In the country west of Hyderabad the Nari beds lie directly upon the Meting Limestone, the Laki Limestone being absent.[5] West of the Laki range, throughout Lower Sind, the Nari beds are exposed almost wherever the base of the Gaj group is seen ; they vary in thickness westwards, and the Hab valley consists entirely of these strata. In southern Sind, however, there is no longer any marked distinction between the subdivisions of the Tertiary such as that seen in the Kirthar range ; in this area the scanty development of the Kirthar, and with it the disappearance of the normal facies of the Lower Nari with its limestones, makes it difficult to draw a dividing line between the Nari and the beds below since both have assumed the flysch facies. Obscure as this line sometimes is, the calcareous shales of the Laki, with their characteristic nummulites, are usually distinguishable from the massive Upper Nari sandstones. Lower Nari fossils appear to be present in the Hab river beds, and here also the Kirthar is to be found,[6] but on the Baluchistan side of the frontier ; both formations have here assumed the flysch facies.

In Baluchistan the Nari is unconformable towards the Kirthar. In Sarawan, where it consists principally of gypsiferous clays of

[4] E. Vredenburg, Rec. 34, 173-174 (1906).

[5] W. L. F. Nuttall, Q. J. G. S., 81, 419 (1925).

[6] The upper Kirthar is shown on Vredenburg's map (Rec. 38, pl. 12 (1909) or Pal. Ind., New Ser., Vol. III, No. 1 Fig 9 (1909) on the west side of the Hab Valley, but may be due to an accidental failure on his part to make an intended correction of the original views of Blanford. In Records, Vol. 38, pages 198-199, he records the presence of Lower and Middle but not Upper Kirthar in the Hab valley ; on another page he speaks only of Lower Kirthar in the Hab river area, and "the enormous gap in time between the two successive geological formations, one being the Lower Kirthar, the other the Upper Nari".

sandstones, and of limestones which are usually brown, it is exposed chiefly in the foothills bordering the western side of the Shir-i-nab and Manguchar valley, as well as in the Drang valley and other synclinal valleys west of the Nagau range. In Jhalawan it consists largely of massive sandstones resting on a considerable thickness of massive limestones which are usually of a pale colour; here it is extensively developed along the Mula valley.[7] These beds in Jhalawan and Sarawan are described by Vredenburg as crowded with lepidocyclines and specimens of *Nummulites intermedius*, and corresponding to the bulk of the Kojak Shales of the flysch region.

In its normal facies the Lower Nari in some places consists almost entirely of brown and yellow limestones; more frequently the limestone bands are subordinate, the mass of the rocks being made up of dark shales, and brown, rather thinly-bedded, fine sandstones. The limestone bands are often confined to the base of the stage, and always diminish in abundance and thickness upwards; nevertheless they are occasionally found at the top of the stage. Their brown or yellow colour is typical and usually distinguishes them from the white Kirthar limestones of the underlying formation. It is quite possible however, that these massive white limestones belong in reality to the Kirthar and not to Nari.[8] Besides their different fossils another feature which distinguishes these limestones from those of the Kirthar is the comparative thinness of the bands caused by intercalations of shale and sandstone, which become thick towards the upper part of the stage. The distinctive fossils are *Nummulites intermedius* and *Lepidocyclina dilatata*, and the principal exposures of the stage are in the northern portion of the Kirthar range and in the hills between Nal and the Las Bela plain.

The Lower Nari beds pass gradually up into the coarser, massive, thick-bedded, often gritty sandstones of the Upper Nari. On the flanks of the Kirthar range a few bands of clay, shale or ironstone are interstratified with the sandstones, and bands of conglomerate are occasionally seen; the bulk of the stage, however, consists of a rather soft, grey sandstone with pale brown ferruginous markings.[9] The principal fossils of the Upper Nari are *Ostraea angulata* and *Lepidocyclina dilatata*; this stage is exposed chiefly in the lower slopes east and west of the Kirthar range, in the valleys between the Kirthar, Bhit, Badhra and Laki ranges, in the valleys of the upper Baran, of the Hab and of the Khand rivers, and in most of the low ground from Bula Khan's Tana to Jungshahi.[10].

The Upper Nari, which corresponds to the Chattian (Upper Stampian) but may perhaps transgress to a slight extent into the Aquitanian, forms in most sections a large proportion of the series. It has proved devoid of the vertebrate remains found in the

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[7] E. Vredenburg, Rec. 38, 195-196 (1909).

[8] According to Vredenburg, the lowest Nari Limestones are often white and very massive (Pal. Ind. New Ser. Vol. 3, No. 1, table facing p. 7 (1909).

[9] G. E. Pilgrim, Rec. 37, 147 (1908).

[10] Pal. Ind. New Ser. Vol. 3, No. 1 table facing p. 7 (1909).

succeeding Gaj, while marine fossils are limited to certain horizons and consist chiefly of *Lepidocyclina dilatata* unaccompanied by mollusca;[11] one of these horizons has been noted 500 feet above the base of the sandstones. Plant fragments have frequently been recorded in the shales and clays which are occasionally intercalated among the sandstones, while the latter themselves sometimes show ill-marked fucoid impressions.

The Kojak Shales.—The change from a calcareous to a flysch facies, described in the case of the Eocene of Baluchistan, also affects the Oligocene. In the north, the Zhob and Pishin valleys form the dividing line which separates the flysch to the north from the calcareous facies to the south. From the Quetta-Pishin district southwards the flysch extends along the western borders, of Sarawan, Jhalawan and Las Bela, and occupies the greater part of the Makran. The eastern limit of the flysch is formed by the Gurgina valley by the calcareous ranges extending from Nimgarh to Maraf and thence to Kodak and Greshag, by the calcareous ranges from Nal to Wad and Wadinghar, and finally by the alluvial plain of Las Bela.[12] It is probably many thousands of feet in thickness, but is so disturbed that no accurate estimate seems possible.[13] The flysch covers a considerable area and consists mainly of a monotonous succession of folded sandstones and shales of greenish colour known as the Kojak Shales.[14] This formation, named after the Kojak Pass over the Kojak (Khwaja) Amran range separating Baluchistan from Afghanistan, above the railway near Chaman in the Quetta-Pishin district, is mostly of Oligocene age, and has yielded Oligocene fossils from numerous localities.[15] The topography is one of innumerable, close-set parallel ridges. Unlike the calcareous region, the hill-ranges of the flysch usually occur along synclines, the intervening low ground being occupied by anticlines, along the axes of which mud volcanoes are sometimes seen in Las Bela and the Makran. In Lus a number have been described which do not appear to be subject to paroxysmal eruptions and attain a considerable size, the largest being over 300 feet in height. How far this is due to the absence of explosive disturbance, to a greater constancy of the vents, or to the rainless nature of the climate, is not clear. In most respects they resemble those already described in the last chapter, except that no oil seepages are known, the hydrocarbon manifestations being limited to gas. In the vicinity of the Makran coast the argillaceous rocks, which have elsewhere been compressed into shales or slates, have remained in the state of a friable clay, whose outcrop is occupied by a complicated network of innumerable, ramifying ravines; in the interior parts the rocks are crushed and disturbed. The development of slaty cleavage, together with the paucity of fossils, in the Kojak Shales

[11] E. Vredenburg, Mem. 50, 4 (1925).

[12] E. Vredenburg, Rec. 38, 202 (1909).

[13] Gen. Rep. (1898-99), p. 66.

[14] E. Vredenburg, Rec. 38, 202 (1909).

[15] Rec. 34, 89, footnote (1906).

north of the Zhob, was responsible for their confusion with the slates of Triassic age on the south side of the valley.

The Kojak Shales are not only well exposed in the Kojak pass in Afghanistan, but cover a considerable area in southern Afghanistan, including probably the Toba plateau. In the Ghaziaband Pass and range they are much contorted and disturbed by many small faults. In the Pass, where they are well seen, they form a great thickness of drab, often banded clay shales. Some of these beds are extremely fine in texture, have a silky touch, and split into leaf-like fragments which occasionally show fucoid markings on the partings. These shales alternate with sandy varieties and thin-bedded sandstones with traces of *Ostraea*. They pass up insensibly into a sandstone group in which the silky shales have survived to the extent of forming thin partings between thicker beds of sandy shale and sandstone. The sandstone, brownish grey in colour, unfossiliferous and rather fine in grain, increases in importance upwards and predominates over the other beds. It is overlain conformably by what Griesbach describes as a "nummulitic limestone." This is a concretionary limestone, usually dark blue or grey in colour but in places reddish brown, with "numerous large species of nummulites", which may perhaps include lepidocyclines.

The Nari of northern Baluchistan.—In the Bugti Hills the Lower Nari, with *Nummulites intermedius* and a *Pecten,* appears to be represented by a thin band of limestone, sufficient to form a physiographical feature. On the south side of the Pir Karoh, these beds take the form of very ferruginous calcareous sandstone, in some places glauconitic, lying unconformably upon beds belonging to the lower part of the Middle Kirthar, and followed by an estuarine phase of the Gaj.[16]

An outlying patch of both the marine Lower and the fresh-water Upper stages of the Nari occurs at Bibi Nani (Bibiani) near Quetta,[17] younger stage in the form of grey sandstones and mottled beds. Lower Nari beds have also been recognised in both the Lower and upper Zhob valleys,[18] in the lower Zhob valley, among the Nari fossils accompanying *Nummulites intermedius* and *Lepidocyclina dilatata* is an *Ostraea* indistinguishable from *O. turkistanensis* Rom., and oyster identified also at Khwaja Kalandar in Afghanistan.

Fauna of the Nari.—The Upper Nari, therefore, is partly marine and partly fluviatile, the former facies preponderating in Sarawan. Jhalawan and the Makran, the latter in Sind and the Bugti area. The marine phase in Sind and Bugti is most conspicuous in the earlier part of the stage, but there was a noticeable reversion to marine conditions towards the end; the latter ushers in the Gaj, the boundary between the two being ill-defined.

[16] W. L. F. Nuttall, Rec. 59, 118, (1926); G. E. Pilgrim—Pal. Ind. New Ser. Vol. 4, No. 1, p. 2 (1912). This estuarine phase of the Gaj, together with the fresh water beds overlying it, was at first referred to the Upper Nari.

[17] E. Vredenburg, Rec. 31, 162-163 (1904); Rec. 34, 268 (1906); 36, 320.

[18] E. Vredenburg, Rec. 31, 162-163 (1904); Rec. 34, 268 (1906); 36, 320 (1907); Gen. Rep. 1898-9, 62; Gen. Rep. 1901-02, 32.

The few marine fossils found among the Upper Nari sediments are all known in the Lower stage, so that the marine fauna of the Nari is best considered as a whole. Some forms pass from the Kirthar into the Nari, but the Nari fauna as a whole shows an unmistakable break with that of the Kirthar below—a break due to the general absence not only of the Upper Eocene (Auversian, Bartonian and Ludian) but also of the Lower Oligocene (Sannoisian or Lattorfian). The most marked change is seen in the foraminifera, which are few in species and not found in the lower beds of the Gaj.[19] The Nari is characterised by an abundance of lepidocyclines and shares this feature with the following Gaj series. All the Nari forms appear to belong to one species, *Lepidocyclina* (*Eulepidina*) *dilatata* (Mich.) synonymous with "*Orbitolites mantelli* Cart.", "*Orbitoides dilatata* Mich.", "*Orbitoides papyracea* Boub"., "*Orbitoides fortisi* ?",[20] but specimens in the Lower stage differ slightly from those in the Upper. The former are frequently saddle-shaped, characterised by a central protuberance, and usually stouter than those in the Upper Nari, which are characterised by having a diameter not exceeding 60 mm. Upper Nari forms are predominantly discoidal and often attain a diameter of 10 cm.[21]; these, according to Vredenburg, are the *L. elephantina* of Mich., probably identical with the Burmese form described by Carter as *Orbitolites mantelli*, var. *theobaldi*, which reaches a diameter of 13-16 cm. (5 or 6 inches.)[22] *L. dilatata* is a European form and is found with *Nummulites intermedius* in the Lower Asmari Limestone of Persia.

The Nummulites are fully reticulated, with a transverse lamina in the structure of the *filets cloisonnaires*, a character marking an advanced stage in the evolution of the genus in India as it does in Europe.[23] The genus has also become reduced to three or perhaps only two true species, namely :

FORAMINIFERA.

Nummulites intermedium d'Arch. (characteristic of the Chattian-Lattorfian of Europe, formerly known in India as *N. sublaevigata*, and the equivalent of *N. subbrongniarti* of Java and Borneo),

Nummulites fichteli Mich., the megalospheric and associated form of the preceding,

Nummulites clipeus Nutt. (found so far only in western Cutch),[24]

Nummulties subclipeus Nutt. (megalospheric form of *N. clipeus*),

Nummulites vacus ? (a provisional but abundant species).

Lepidocyclina makes its appearance very low in the Nari, often at the very base, and frequently accompanies *Nummulites intermedi*

[19] P. M. Duncan and P. Sladen, Pal. Ind., Ser. 14, Vol. 1, No. 3, p. 4-5 (1882-86).

[20] Nuttall records another species of *Lepidocyclina* resembling L. *praemarginata* Douv. except that it is megalosphesic, and distinct from *L. dilatata*; only one specimen of this form is known however (Ann. Mag. Nat. Hist. Ser. 9, Vol. 17 337 (1926).

[21] W. L. F. Nuttall, Ann. Mag. Nat. Hist. Ser. 9, Vol. 15, 661—666 (1925).

[22] Ann. Mag. Nat. Hist. Ser. 6, Vol. 2, pp. 342-348 (1888).

[23] W. L. F. Nuttall, Ann. Mag. Nat. Hist., Ser. 9, Vol. 15, 661 (1925).

[24] W. L. F. Nuttall, Ann. Mag. Nat. Hist., Ser. 9, 15, 661 (1925).

and *N. vascus* throughout the entire thickness of the Lower Nari; whole beds of limestone towards the base of this stage are sometimes made up entirely of these three foraminifera. Lepidocyclines are in certain regions also abundant in the Upper Nari but are generally unaccompanied by the Nummulites.[25] *Nummulites intermedius* characterises the European Oligocene (Lattorfian to Chattian) and is found as well in Borneo, Java and East Africa. The co-existence of reticulate nummulites and lepidocyclines is a feature of the Stampian. Unlike the mutual relationship of the Kirthar and Nari, there are many fossils common to the Nari and Gaj, and the one series, in fact, passes up into the other.

In addition to the foraminifera already enumerated, the Nari has yielded the following fauna:

ALCYONARIA.[26]

Trochocyathus burnesi Haime,
Trochocyathus nummiformis Dunc., and two varieties,
Trochocyathus nariensis Dunc., and a variety,
Trochocyathus cyclolitoides M. Edw. & Haime,
Blanfordia nummiformis Dunc.,
Stylophora pulcherrima d'Arch.,
Trochosmilia varicosa Reuss,
Trochosmilia oldhami Dunc.,
Trochosmilia dharanensis Dunc.,
Stylocoeni taurinensis M. Edw. & Haime,
Montlivaltia vignei d'Arch. & H., (an exclusive Nari form),
Dasyphyllia gemmans Dunc.,
Rhabdophyllia nariensis Dunc.,
Leptoria concentrica Dunc.,
Maeandrina medlicotti Dunc.,
Prionastraea insignis Dunc.,
Prionastraea tenuiseptata Dunc.,
Cycloseris perezi M. Edw. & Haime,
Cyclolites orientalis Dunc.,
Litharaea nodulosa Dunc.

ECHINOIDEA.[27]

Cidaris verneuilli (a typical Nari form),
Coelopleurus equis Agass. (=*C. coronalis* Klein),

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[25] E. Vredenburg, Rec. 34, 90 (1906).

[26] P. M. Duncan, Pal. Ind., Ser. 14, Vol. 1, Pt. 2, 68-69 (1880). Whether, as in the case of the echinoids, this list requires some revision, is not known (see note on next page).

[27] The echinoids were determined before the correct boundaries of the Tertiary stages have been accurately defined. The confusion thus caused in the case of Ranikot, Laki and Kirthar has been corrected by Vredenburg (Rec. 34, 172, (1906). Those of the Nari Series were not revised by that observer perhaps because there appear to have been fewer mistakes made in identifying the boundaries of the Nari than there were in the case of the Eocene stages. Although the lower Nari was erroneously spoken of as conformable to the Kirthar in northern Sind, and although in some of the coastal sections it was impossible in the field to distinguish exactly between the Tertiary stages, it is stated that the faunas are different and that the various groups can be separated by their fossils. The chances are, therefore, that the echinoids and corals listed under the headings of Nari and Gaj are rightly so designated. Nevertheless it is possible that one or two

Coelopleurus pratti d'Arch. & H.,
Coelopleurus forbesi d'Arch. & H., (a typical Nari form),
Clypeaster simplex Dunc. & Sl.
Clypeaster monticulifera Dunc. & Sl.,
Clypeaster apertus Dunc. & Sl. (classed as Eocene, but since its actinal surface is covered with *Nummulies intermedius*, it must be Oligocene),[28]
Clypeaster profundus Dunc. & Sl. (typical Nari form),
Echinolampas difficilis Dunc. & Sl.,
Echinolampas d'Archci Dunc. & Sl.,
Echinolampas rodakensis Dunc. & Sl.,
Echinolampas discoideus d'Arch., and three varieties,
Echinolampas placenta Dunc. & Sl.,
Echinolampas tumida Dunc. & S., and a variety,
Eupatagus (*vel Euspatangus*) *rostratus* d'Arch. (exclusively Nari),
Schizaster granti Dunc. & Sl.,
Schizaster baluchistanensis Vred. (typical Nari form).
Temnechinus rousseaui d'Arch. (typical Nari form).
Moira primaeva Dunc. & Sl., (typical Nari form),
Breynia multituberculata Vred. (Typical Nari form; d'Archiac's *Br. carinata*.).[29]

LAMELLIBRANCHIATA.

Arca semitorta Lam. (Baluchistan ; found also in the Gaj),
Nucula narica Vred.,
Lithodomus sublithophagus d'Orb. (Baluchistan and Sind ; Eocene of Paris; Oligocene of N. Italy),
Ostraea angulata J. de C. Sow. (Cutch and Sind ; also in the Gaj),
Ostraea cubitus Desh. (Sind),
Ostraea fraasi Mayer-Eymar (Baluchistan, Cutch and Sind),
Ostraea protoimbricata Vred. (Sind),
Ostraea longirostris Lam. (Baluchistan),
Pecten (*Amussiopecten*) *labadyei* d'Arch. & H. (Baluchistan and Sind ; the commonest *Pecten* in both the Nari and Gaj),
Chlamys tauroperstriatus Sacco, var. *persimplicula* Sacco (Bal.),
Cardita arduini Brongn. (Sind),
Cardita (*Venericardia*) *laurae* Brongn. (Sind),
Cardita (*Glans* ?) *rovereti* Vred. (Baluchistan),
Lucina (*Dentilucina*) *narica* Vred. (Baluchistan),
Lucina (*Gibbolucina*) *deperdita* Mich. (Baluchistan),
Lucina (*Linga*) *columbella* Lam. (Baluchistan ; also in the Gaj),
Diplodonta incarta d'Arch. & H., var, *norica* Vred, (Sind),
Crassatellites (*Crassaltella*) *sulcata* (Sol.) (Sind ; also in the Gaj, Barton beds of England),
Crassatellites (*Crassatella*) *carcarensis* Mich. (Sind ; a variety occurs in the Oligocene of the Vicentino),
Cardium (*Discors*) *naricum* Vred. (Sind ;=*C. anomale* of Fuchs, Vicentino),
Cardium (*Nemocardium*) *bhagothorense* Vred. (Sind),
Cardium (*Trachycardium*) *verrucosum* Lam. (Baluchistan ; Upper Eocene of the Paris basin ; Oligocene of Liguria and the Vicentino),
Cardium (*Trachycardium*) *sindiense* Vred. (Sind),

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forms belonging to the Kirthar may have crept into the Nari list, in any case the determinations were made in 1886 and need revision (Pal. Ind., Ser. 14, Vol. 1, No. 3, 249). The confusion in the case of Tertiary of Cutch, and Kathiawar was considered by Vredenburg to be irremediable, and the fossil lists referring to these regions have been omitted. The last four echinoids in the above list are added on the authority of Vredenburg, as are also *Cidaris verneuilli, Clypeaster profundus* and *Cl. apertus*. These echinoids indicate an upper Oligocene age (Pal. Ind., Ser. 14, Vol. 1, 246 (1882-1886).

[28] Rec. 34, 90-91 (1906).

[29] Rec. 34, 90 (1906).

Cytherea (Callista) splendida Mer. (Sind; Paris basin),
Cytherea exintermedia Sacco (Sind; Oligocene of Europe),
Cytherea (Pitar) porrecta Koen. (Bal.; doubtful in Sind),
Venus (Ventricola) multilamella (Lam.) (Sind and Baluchistan),
Venus (Omphaloclathrum) puerpera Linn., var. *aglaurae* Brongn. (Sind, Baluchistan and Cutch, a common Oligocene and Aquitanian form in N. Italy),
Venus (Clementia protopapyracea Vred. (Baluchistan),
Solenocurtus carinata Duj., var. *oligolaevis* Sacco (Sind).

GASTROPODA.

Acera narica Vred. (Sind),
Scaphander oligoturritus Sacco (Sind; a Ligurian form),
Terebra narica Vred. (Baluchistan; fore-runner of the Recent *T. crenulata* (Linn),
Terebra subtessellata d'Orb., var. *oligocenica* Vred. (Sind species in Liguria),
Terebra (Myurella) quettensis Vred. (Baluchistan and Burma,
Pleuroforma (Hemipleurotoma) yenanensis Noetl. var. *narica* Vred. (Sind). species in Burma; close to *Pl. odontophora* v. Koen, in the Oligocene of Lattorf in Saxony),
Pleurotoma (Hemipleurotoma) bonneti, var. *bhagothorensis* Vred. (Sind),
Conorbis dormitor (Sol.) var. *sindiensis* Vred. (Sind),
Conorbis dormitor var. *bhagothorensis* Vred. (Sind),
Conus (Lithoconus) ineditus Mich. (Sind and Burma; one of the commonest fossils in the Oligocene of Liguria; close to the living *C. malaccanus* Hwass),
Trigonostoma indicum Vred. (Sind),
Uxia narica Vred. (Sind),
Olivella elegantula Rov. (Sind; Oligocene of Liguria),
Ancilla (Sparella) indica Vred. (Sind; close to Noetling's *A.* cf. *vernedei* Sow.),
Harpa (Eocithara) narica Vred. (Sind; close to *H. elegans* Desh. from the Upper Eocene of Paris.),
Marginella (Glabella) narica Vred. (Sind),
Athleta (Volutospina) sindiensis Vred. (Sind),
Lyria anceps (Mich.) (Sind and Baluchistan; Oligocene of Liguria),
Fusus (Aptyxis) reticulatus Vred. (Sind),
Euthriofusus subregularis (d'Arch. & H.) (Sind),
Euthriofusus subregularis var. *narica* Vred. (Sind),
Streptochetus pseudo-waelii Vred. (Sind;=a form found at Mainz in the Oligocene),
Latirus (Lathyrus) sindiensis Vred. (Sind; very close to *L. retrorsicosta* (Sandb.) from the Oligocene near Mainz),
Turbinella episoma (Mich.) (Sind and Baluchistan; Oligocene of Liguria; very close to *T. fusus* Sow., now living in the Andaman seas),
Cominella annandalei Vred. (Sind; a Recent but rare genus in Asia),
Murex (Haustellum) naricus Vred. (Sind),
Murex (Muricantha) ighinoe Bellardi (Sind; Oligocene of Liguria),
Tritonium (Sassia) indicum Vred. (Sind; Oligocene of Belgium, Paris and Germany; very close to *Tr. flandricum* de Kon., a common fossil in the Bracklesham and Barton beds of England),
Persona (Distortrix)reticulata (Linn.) cum var. *subclathrata* d'Orb. & *metableta* Cossm. (Sind; Oligocene and Miocene of Burma; New Tertiaries of Karikal; Upper Miocene and Pliocene of Java; Indian shell identical with that from the Vicentino),
Hindsia nivea (Gmel.) var. *narica* Vred. (Sind; species living in the Bay of Bengal),
Hindsia nivea var, *bhagothorensis* Vred. (Sind),
Ranella tubercularis Noetl. (Sind; Burma),
Cassidea mamillaris Grat., var. *nummulitiphila* Sacco (Sind; Oligocene of Liguria),

Cassidea (*Semicassis*) *oligocalantica* Vred. (Sind ; very close to *C. calantica* Wesh. from the Upper Eocene of Paris),

Cassidaria (*Sconsia*) *beyrichi* (Mich.) (Sind),

Pyrula condita Brongn. (Sind and Baluchistan ; one of the commonest fossils in the Oligocene of India, or the Oligocene and Miocene of Europe; =Noetling's *Ficula theobaldi from* Burma),

Cypraea (*Bernavia*) *subexcisa* Braun (Sind and Baluchistan ; corresponding beds in Burma ; Gaj of Sind ; Oligocene of Liguria ; Vicentino),

Cypraea (*Erosaria*) *sindiensis* Vred, (Sind),

Rostellaria (?) *sindiensis* Vred. (Sind),

Rimella subrimosa d'Orb., var. *narica* Vred. (Quetta-Pishin),

Terebellum (*Seraphs*) *naricum* Vred. (Sind ; sub-genus very rare in Asia),

Cerithium (*Bellardia*) *naricum* Vred. (Sind ; *Bellardia* is an Eocene sub-genus),

Cerithum (*Gourmaya*) *baluchistanensis* Vred. (Baluchistan).

Cerithium (*Ptychocerithium*) *ighinai* Mich. (Lower Nari of Sind ; Oligocene of the Vicentino and Lesbarritz),

Cerithium (*Ptychocerithium*) *perlamellosum* Vred. (Baluchistan & Sind),

Cerithium (*Ptychocerithium*) *sindiense* Vred. (Sind),

Cerithium (*Ptychocerithium*) *haimei* Vred. (Sind),

Cerithium (*Ptychocerithium*) ? *tricingulatum* Vred. (Sind),

Cerithium (? *Chondrocerithium*) *bhagothorensis* Vred. (Sind),

Potamides (*Tympanotomus*) *laevis* Vred. (Sind),

Potamides (*Telescopium*) *charpentieri* de Bast. (Baluchistan ; also in the Gaj ; Oligocene of France and N. Italy),

Turritella narica, Vred.,

Turritella narica, Vred. (Sind and Baluchistan).

Turritella narica, var. *baluchistanensis* Vred. (Sind and Baluchistan),

Turritella pseudotethis Vred. (Sind).

Turritella bhagothorensis Vred. (Sind),

Turritella asperula Brongn. (Sind ; very common in the Oligocene of S. W. France and N. Italy),

Turritella conofasciata Sacco (Sind),

Turritella desmarestina de Bast. (Baluchistan and Sind),

Turritella tipperi Vred. (Baluchistan),

Turritella strangulata Grat. (Baluchistan ; common in the Oligocene of S. W. France and N. Italy),

Turritella magnasperula Sacco, var. *crassocingulata* Vred. (Baluchistan= *Noetling's T. affinis* and *T. affiniformis* from Burma ;=Sacco's *Haustator magasperulus* of N. Italy),

Turritella (*Protoma*) *deshayesi* d'Arch. (Baluchistan and Sind ;=*Pr. cathedralis* Brogn., *var. sexplicata* Sacco ;=*Pr. excathedralis* Rov.;=*Pr. quadricanaliculata* Sand. from the oligocene of S. Bavania ; exclusively Nari),

Turritella (*Protama*) *retrodilatatum* Vred. (Sind),

Turritella (*Protoma*) *renevieri* (d'Arch & H.) (Sind ; close to *Pr. deshayesi*),

Tarritella (*Protoma*) *subrenevieri* Vred. (Baluchistan),

Solarium naricum Vred. (Sind),

Hipponyx cornucopiae Lam., *var. narica* Vred. (Sind ; species from the Middle and upper Eocene of the Paris basin),

Natica (*Naticina*) sp. (? Nari),

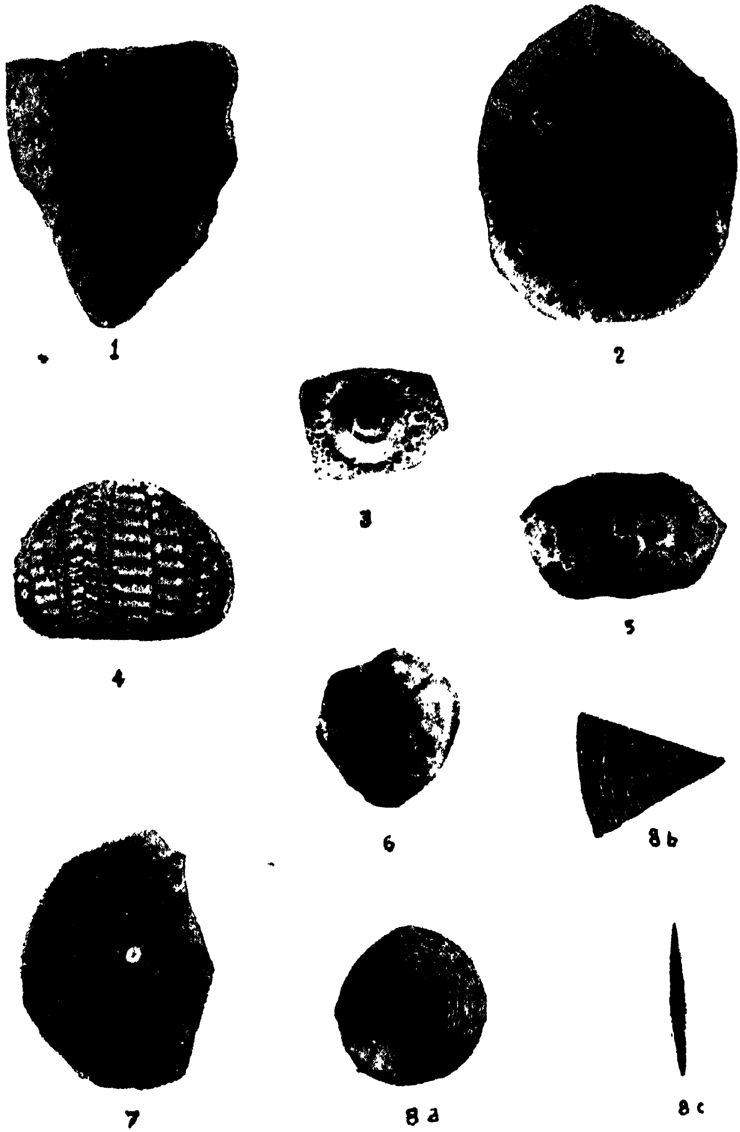
Sigaretus aquensis Recl., var. *praecidens* Sacco (Baluchistan and Sind ; Oligocene of N. Italy),

Ampullina (*Globularia*) *gibberosa* (Grat.) (Sind ; one of the commonest fossils in the Oligocene of Europe ;=*Natica decipiens* d'Arch. & H.),

Ampullina (*Megatylotus*) *crassatina* Lam. (Baluchistan),

Ampullospira (*Euspirocrommium*) *Oweni* d'Arch. & H. (Sind ;=*Phasianella* Oweni d'Arch. & H.),

Turbo (*Olearia*) *protocepoides* Vred. (Baluchistan and Sind ; close to the living *T. cepoides* Smith),



OLIGOCENE FOSSILS

1 *Montlivaltia vignei* d'Arch. & Haime (X1). 2. *Clypeaster profundus* d'Arch.& Haime (X2-1/2) 3. *Cidaris verneuili* d'Arch. (X1). 4. *Temnechinus rousseaui* d'Arch. (X2) 5. *Coelopleurus forbesi* d'Arch. & Haime (X1). 6. *Moira primaeva* Dunc. & Slad. (X1). 7. *Lepidocyclina dilatata* (Micheloti) (X16). 8a, b & c *Nummulites intermedius* d'Arch. (X1).

G. S. I., Calcutta.

Turbo (*Senectus*) *radiatus* Gmel., var. *naricus* Vred. (Sind; species living on the Indian coasts),
Turbo (*Marmorostoma* ?) *pseudoundulatus* Vred. (Baluchistan, close to *T.* (*M.*) *undulatus* Martyn from Australia),
Trochus (*Tectus*) *lucasianus* Brongn. (Baluchistan and Sind; one of the commonest fossils in the Oligocene of N. Italy; close to the living *T. triseralis* Lam. from the eastern seas),
Tugurium subextensum d'Orb. (Sind).

CEPHALOPODA.

Aturia narica Vred. (near the base of the Nari in Sind).

The fresh-water fauna found in parts of the Upper Nari[30] includes the following mollusca, none of which is identical with living forms, but two of which are allied thereto, one so closely as to be scarcely distinguishable.

GASTROPODA.

Melania pseudopiscopalis Blanf. (very close to the *M. episcopalis* now inhabiting Burma and N. E. India),
Melania gradata Blanf.,
Melania gradata, var. *major* Blanf.,
Viviparus (*Paludina*) *bugticus* Blanf.

LAMELLIBRANCHIATA.

Unio vicaryi Blanf.,
Unio cardiiformis Blanf. and variety,
Unio cardita Blanf.
Unio pugiunculus Blanf. (close to the living forms, *U. pugio* Bens. from Burma, and *U. gravanus* from China and *U. ingallsianus* Lea from Siam).

The Nari as a whole corresponds approximately with the Stampian of Europe, its nearest faunal equivalent being the Oligocene of Liguria in northern Italy. The Lower Nari would thus coincide more or less with the Rupelian and the Upper Nari with the Chattian. Vredenburg has recently suggested that the Lower stage may represent either the Lattorfian or the Rupelian [31] or both these stages. An assumption that the Lower Nari includes part or the whole of the Lattorfian would reduce the unconformity between the Kirthar and the Nari. While the Ranikot fauna of northwestern India and Tibet is unlike any corresponding assemblage in Europe, the Laki and Kirthar faunas show increasing resemblances with their European equivalents, and these resemblances reach a maximum in Lower Nari times, a large number of Oligocene species being common to the two regions. During the Oligocene period, there appears to have been a marine transgression which established for a time a widespread oceanic connection between the Indian and European seas. In the Bugti hills, Loralai and Dera Ghazi Khan districts, prior to the deposition of the Oligocene the Eocene beds were raised and eroded and the upper part of the Middle as well as the Upper Kirthar removed.[32]

[30] Wrongly identified as Lower Siwalik (Mem. 20, 233 (1883).
[31] The term used is "Stampian", but the context shows that this was not meant to include the Chattian.
[32] W. L. F. Nuttall, Rec. 59, 117 (1926).

In Sind and Baluchistan the marine stage established in early Oligocene times was gradually succeeded by fresh-water conditions, as land again arose.

CUTCH.

In northwestern Cutch, exposed in an arc shaped outcrop a dozen miles or so north of Jakhan, the Nari is represented by the "Arenaceous group" of Wynne.[33] This group is described as variable, inconstant and sometimes entirely absent. Where found, it is characterised by irregular, current-bedded sand or friable sandy shales, generally white but streaked with iron-stained laminae; these beds, the sands of which contain impressions of several varieties of exogenous leaves, may be tentatively correlated with the Upper Nari. Below them Wynne records dun-coloured and blue, finely laminated clays in which a few fossils, including casts of a small doubtful *Donax* and the carapace of a very small crab were found. These clays probably form part of the Lower Nari, to which also belongs a 10-foot bed of limestone noted by Nuttall as unconformably overlying the lower part of the Middle Kirthar and containing *Pecten laevi-costatus* Sow. and abundant examples of *Nummulites intermedius, N. clipeus* and their megalospheric forms.[34] This Lower Nari limestone is marly, occasionally glauconitic and of a white to creamy yellow colour, and forms the base of Wynne's Arenaceous group. No doubt from the same horizon comes the specimen of *Clypeaster apertus* Dunc. & Sl. which Vredenburg found to be covered with *Nummulites intermedius*, as well as another echinoid, *Breynia multituberculata* Vred. Oligocene fossils in Cutch tend to attain unusual dimensions, as exemplified by the *Breynia* and the *Nummulites intermedius*, the latter sometimes measuring 30 mm. in diameter.[35]

THE SULAIMAN RANGE.

From the Bugti hills through Drug and at least as far as Fort Munro the Nari is absent, the Middle Kirthar being followed unconformably by the Gaj. Beyond the Fort, in the southern portion of the Sulaiman range, 2,000 feet of sandstones and clays have been referred by Blanford to the upper Nari but are considered by La-Touche to occupy a higher stratigraphical position than his subdivision 12, which Vredenburg identifies as the flysch facies of the Nari. These sandstones and clays in the southern Sulaiman hills, therefore, may represent either the Gaj or the Upper Nari; they occur between a thick series of beds correlated with the Spintangi stage and 5,000 feet of the Lower Siwaliks. La Touche's "subdivision 12" in the northern part of the range is also 2,000 feet in thickness and occurs between what appears to be either a thin representative of the Upper Kirthar or the Upper Laki limestone below and the Lower

[33] W T. Blanford, Mem. 17, 67 (1879); Mem. 9, 78 (1872).
[34] Ann. Mag. Nat. Hist., Ser. 9, Vol. 15, 662 (1925).
[35] Rec. 34, 90, 91 (1906).

Siwalik sandstones and clays with mammalian bones above;[36] it consists of olive shales and clays. With regard to its age we again have the choice between Upper Nari and Gaj, its base consisting of a brown marine limestone which has yielded fossils identified by Tipper as of Nari or Gaj age.[37]

In the more northerly parts of the Punjab there is no definite record of the presence of any representative of the Oligocene.[38] The formation is represented in Persia by Pilgrim's Khamir series and is well seen in the country surrounding Bandar Abbas,[39] where it has yielded the following Oligocene fossils, including several Nari forms: *Nummulites intermedius, N. fichteli, Eupatagus* cf. *rostratus, Ostraea* cf. *protoimbricata*, and *Pecten* (*Amussiopecten*) cf. *labadyei* (d'Arch. & H.).[40] The series has been identified by Pilgrim further to the east around Geh, and in the Oman peninsula.

The Oligocene has not been identified in the Hazara mountains, but in the Himalaya is probably represented to some extent by the uppermost horizons of the Subathu series, which has been described in the previous chapter.

ASSAM.

The Barail series of Lower Assam.—In lower Assam the Jaintia series of P. Evans, including the greater part of the Eocene, is succeeded by the Barail series, which in its turn is followed stratigraphically by the Surma series. The Barails, with a maximum thickness of 15,000 feet, are believed to include the Upper stages of the Eocene —the Auversian and Bartonian—and the Lower Oligocene or Lattorfian. The Surma series, attaining a maximum thickness of some 13,000 feet, is thought to be astride the Oligocene and Miocene and to represent approximately the Stampian and Aquitanian.

From the descriptions of Evans[41] the Barail series, named after the Barail range in north Cachar, is mainly an arenaceous formation and is found lying with no visible discordance upon either the Jaintia or the Disang series; it covers a large area in Assam, and is distinguished from the younger Surma series by the abundance of the carbonaceous material it contains.

In the type area, southeast of the great Haflong-Disang fault, the outcrop occupies a country of remarkably steep hills, and stretches from near Jaintiapur eastwards across the Jatinga gorge and northeastwards to the vicinity of Kohima, a total distance of some 130 miles. The last 90 miles, from the Jatinga to Kohima, form an im-

[36] Rec. 26, 82 (1893).

[37] E. W. Vredenburg, Rec. 36, 252 (1907).

[38] Marine fossils of this age are said to have been collected in the Salt Range (Rec. 36, 252, note (1908), but no occurrence of such beds is mentioned by Gee.

[39] Mem. 48, pt. 2, 78 (1925).

[40] L. R. Cox, Pal. Ind., New Ser. Vol. 22, No. 2, (1936).

[41] Trans. Min. Geol. Inst. India; Vol. 27, 182, (1933).

pressive, forest-clad range with an almost unbroken line of peaks, some of them nearly 10,000 feet in height; from Kohima the outcrop sweeps round to the southeast and south, occupying the high range west of the Kohima-Imphal road, and extending probably for many miles southwards on the west side of the Manipur plain. When traced into upper Assam the beds show an appreciable amount of lateral variation which maintains, however, a constant character. Throughout lower Assam Evans has found it possible to subdivide the series into three well-marked stages which appear to have more than a mere local value. It must be remembered, however, that the boundaries of these and later subdivisions., all of them more or less unfossiliferous, do not everywhere represent the same time planes; they merely indicate the beginning or end of a certain type of deposition which was initiated usually at the head of the Assam valley and progressed slowly westwards and south-westwards, to be followed by another facies of sedimentation commencing in the same place and retreating in the same direction. Similar conditions, it will be seen, obtain in the long Tertiary valley of Burma. Mr. Evans' sub-divisions are:

		ft.
3. Renji stage	massive sandstone	2,900
2. Jenam stage	sandstone, alternating with shale and carbonaceous shale	4,100
1. Laisong stage	bedded sandstone and subordinate shale	8,000

The Laisong stage, varying from 6,000 to 8,000 feet in thickness, consists largely of very hard, grey, thin-bedded sandstones, alternating with hard sandy shales, but include also more massive sandstones and normal shales, the latter occasionally carbonaceous; thin streaks of coal have been noticed in this stage. Oil seepages have been noted by Captain Palmer in the Khasia Hills in beds which would appear to belong to the Laisong stage.[42] There is no visible unconformity between the base of the Laisong and the subjacent Disangs whose shales are, moreover, indistinguishable from the lowest Laisong shales. Some of the best exposures are those in the Jenam river near Laisong.

The Laisong passes up into the much more argillaceous Jenam stage, which is about 3,000-4,000 feet thick, gives rise to low ground, and is made up of shale, sandy shale, carbonaceous and often ironstained shale, together with beds of sandstone similar to the more massive sandstones of the Laisong stage.

The Renji stage, varying rapidly and irregularly from under 2,000 feet to at least 3,000 feet, consists uniformly of hard, ferruginous, usually massive sandstone. Shale is comparatively rare, and the sandstone is seldom thin-bedded. This stage forms the hills north of Badarpur and is responsible for the precipitous Henima scarp, and the magnificent cliffs and peaks of Japvo to the south of Kohima.

The Barails are not recorded in the Garo Hills, where they appear to be overlapped by the Surma series, but they are known to occur

[42] Gen. Rep. Rec. 54, 38 (1922).

in a few localities between the Garo Hills and Jaintiapur, and Nongkulang Hill may be one of these.

The Barails also cover a large area northwest of the Haflong-Disang fault in north Cachar and the Mikir hills, stretching for about 70 miles from near Jaintiapur to the neighbourhood of Lumding, where continuity of the outcrop is broken by the transgression of the overlying Surma beds. Except at its eastern end, this outcrop is characterised by lower dips, and flat-topped, terraced hills, giving rise to a plateau-like topography. Here massive, current-bedded sandstones predominate; argillaceous beds form only a small proportion of the whole, but are more extensively carbonaceous, occasionally gypsiferous, and sometimes yield plant remains. These shales show much iron and sulphur staining, and are associated with springs emitting hydrogen sulphide. Here the base of the series lies upon the Kopili beds with the same apparent conformity and transition as their equivalents southeast of the great fault do upon the Disangs. In an inlier near Lumding the Barails have been reduced in thickness by pre-Burdigalian erosion, and in other parts of the Mikir Hills have been completely removed, with the result that the Surma beds lie directly upon Jaintia or metamorphic rocks.

East and northeast of Lumding, still on the northwest side of the great strike fault, the Barails become more and more disturbed, and the outcrops are split up into long narrow strips or small inliers by a system of strike faults. In facies the beds of this area are said to be transitional between those of lower Assam and those of the upper portion of the province. The longest of these strips stretches from near Nichu Guard to Cholimsen and beyond, and shows an increasing coal content in this direction. A 10-foot seam occurs at Sanis, while the seams at Cholimsen are well known and are equated stratigraphically by Evans with part of the Coal Measures of upper Assam. In the eastern parts of the Naga Hills district and in Manipur a number of outliers of the Barail rocks are seen among rocks believed to belong to the Disang series.

In the Garo Hills, near Adugiri, rusty sandstones, overlying Eocene nummulitic beds, contain poorly preserved impressions and casts of marine lamellibranchs, and may possibly belong to some stage of the Oligocene.[43]

The equivalents of the Barail series in Upper Assam.—In upper Assam, beyond Cholimsen, the Barail series is not exposed continuously but in isolated inliers. Here it can be subdivided as follows, the subdivisions according to Evans, straddling those found further southwest, a result of the marked lateral variation and of the increased importance of the coal deposits:—

Coal Measures	Upper portion (1,000-2,000 ft.)	—Renji (2,000-3,000 ft.)
	Lower portion (9,000 ft.)	—Jenam (3,000-4,000 ft.)
Naogaon stage.	(3,000-5,000 ft.)	—Laisong (6,000-8,000 ft.)

[43] Gen. Rep. Rec. 68, 78 (1934).

The Naogaon Sandstone.—In the Disang river the Disang Shales pass up through interbedded shales and sandstones into hard, grey, fine-grained, thin-bedded, often flaggy sandstones with occasional beds of shale; these have been named by Mallet the Naogaon Sandstone[44] since they form the scarp on which the village of Naogaon (Nakphan) stands on the left bank of the river, in unadministered country W.S.W. of Namsang. These sandstones are again seen some 18 or 20 miles further to the northeast, where they are responsible for both the Dirak peak and the Dirak river gorge; they are also exposed higher up the Dirak near Wangting, in the headwaters of the Namdang, Ledo and Likha streams, and again in the Tipang and Trap rivers. The 10,000 feet exposed in the last-mentioned section is suspected by Evans of being a result of duplication by faulting. Further to the east, the Patkoi scarp above the Nawng Yang lake, is formed of these rocks which below the Pangsau Pass are estimated to be about 3,000 feet thick. In the Naga Hills district the Naogaon Sandstone is a somewhat variable rock, sometimes soft and coarse like the Tipam sandstones, sometimes resembling the finer sandstones of the Coal Measures. It caps the conspicuous hill of Wokha in the bend of the Dayang, where it exhibits a strikingly concretionary structure, while at Mokaokchang, further northeast, it is quarried for building purposes.[45] Towards the southern border of the district, between Samaguting and Kohima, the Naogaon Sandstone, here a thick massive sandstone with occasional thin shale partings, forms the range which contains the peak of Kadiuba; seven miles to the southeast it is again seen in the peak of Siwenuchika, repeated perhaps by folding or faulting.[46] As a rule the Naogaon sandstones are not massive; they form prominent scarps and are indistinguishable from the Laisong beds of Lower Assam.

The Coal Measures.—The Coal Measures of Upper Assam include the coalfields of Nazira, Safrai, Jaipur, Makum (Namdang-Ledo), Namchik and others.[47] Owing to the effects of the unconformity the horizon of the uppermost beds in different areas varies, the equivalent of the Renji stage being either extremely thin or absent altogether. Exposed along the foothills skirting the southern edge of the Brahmaputra alluvium in the Lakhimpur and Sibsagar districts, the Coal Measures consist of alternating sandstones, shales, mudstones and coal seams, with a few thin concretionary layers of earthy, ferruginous limestone or of tough magnesian limestone. Some of the coal seams, especially those forming the base of the uppermost quarter of the

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[44] Mallet placed the Naogaon Sandstone at the top of his Disang Series.

[45] H. H. Hayden, Rec. 40, 286 (1910).

[46] E. H. Pascoe, Rec. 42, 257 (1912).

[47] Evans divides the Coal Measures into two sub-stages, a lower or Baragolai sub-stage, and an upper or Tikak Parbat sub-stage, the distinguishing feature of the latter being the occurrence of workable coal seams at its base. This sub-division though useful for mapping purposes, has no great stratigraphical significance and has been omitted. Thin coal seams are found in the lower sub-stage, while the predominance of arenaceous beds which characterises it is also locally found in the upper sandstones therein giving rise to marked physical features.

stage and mined at Nazira, Namdang and near the Tipang river, are of great thickness and importance. To this stage also the substantial oil occurrences of Assam are probably indigenous. The base of the stage is nowhere exposed, its contact with the Disang beds in this part of Assam being invariably a faulted one.

The sandstones are from fine to medium in grain, the former thin-bedded, the coarser varieties massive and jointed.[48] The shales are frequently carbonaceous and pass on the one hand into coal and on the other a tough clay of a peculiarly intense blue colour, exactly similar to that found in the clays of the oil-bearing Pegu series of Burma. This blue clay is also formed by the weathering of the shale which in this respect differs from the more clunchy Disang shales. The blue colour is a very common feature of the "drillings" brought up in oil wells or ejected from mud vents or gas pools, and may have some connection with the presence of oil.[49] Small quantities of clay ironstone in nodules and layers, as well as minute particles of iron pyrites often accompany the argillaceous sediments and also the coal; from the former considerable quantities of iron used to be extracted under the old native rule. No gypsum occurs in the Coal Measures, but the underground water is salty.

The only organic remains found in these rocks are dicotyledonous leaf impressions. These are numerous and well preserved in the Namdang coalfield but, unfortunately, indicate no precise age. Some have been given by Sir Albert Seward the general term, *Phyllites*, under the name of *Ph. kamarupensis*;[50] and belong to one of the commonest types of tropical or sub-tropical leaves; others—*Phyllites* sp., cf. *Nerium* sp.—closely resemble the oleander. All that can be said as to their age is that they are dicotyledonous and of Tertiary aspect rather than Cretaceous.[51]

The coal of the formation is not a lignite but a true coal, hard, bright brownish black to black in colour, and with irregular or sometimes cubical cleavage; its seams are more persistent than the rest of the Coal Measure strata. Seams of 10, 12 or 15 feet are by no means uncommon, and compound seams containing from 60 to 80 feet of coal stretch for several miles in the Lakhimpur district. Fossil resin is said to occur in the coal, but some at least of this material appears to be allophane.[52] The coal of Assam is of excellent quality, giving off gas and burning readily with considerable flame and great heat, but suffers from two defects, *viz.*, a tendency to crumble, and a high percentage of sulphur. The tendency to crumble means that the coal is placed on the market in a very small state and needs briquetting. Sulphur is present not so much in the form of pyrites but as part of the coal substance, and is therefore not

[48] E. H. Pascoe, Mem. 40, pt. 2, 278 (1914).

[49] Mem. 40, pt. 2, 18 (1914).

[50] This species has been identified in the Coal Measures of the Naga Hills, by Fox, as well as in the same series at Margherita (Gen. Rep. Rec. 61, 18 (1928).

[51] A. C. Seward, Rec. 42, 93-95 (1912)

[52] A. L. Coulson, Rec. 61, 363-366 (1928).

removeable by any physical method. The exceptionally fine coke—it, in many cases, produces—is useless for metallurgical purposes because of the large sulphur content.

The coalfields of Upper Assam.—The most important field is variously spoken of as the Namdang-Ledo, Makum or Margherita coalfield, and coincides with a strip of the Coal Measures between the main Disang thrust-fault and another fault which follows the general line of the Dihing river; between these two fractures the beds are bent into a somewhat asymmetrical syncline,[53] and are exposed for a thickness of 11,000 feet according to Evans. They are seen for a length of twenty miles, from the Tirap to Namsang, where they are cut out by the main reversed fault. The coal mines have been excavated on the northern limb of this well defined syncline, which is narrow and highly inclined to the west but broadens with the decrease in dip eastwards; the area is a highly folded one and there are subordinate flexures.[54] In this type area, workable seams are limited to a small portion of the succession, the lowest being the so-called "thick-seam" or "60 feet seam" averaging 50 feet but in places as much as 80 feet;[55] it is very persistent and, although very occasionally dropping to a minimum of 15 feet, shows little variation over a distance of six miles. Higher up is the 20 feet seam and between the two are thinner seams; near Baragolai the 20 feet seam has suffered erosion over a large area. Much of the coal of this field lies above water-level and can be worked by adits. The reserves above the natural drainage of the Ledo and Namdang streams were estimated in 1900 to be 90 million tons. The reserves below river level must be enormous. Operations on large scale began in 1881, and the output for each of the years 1915 and 1930 exceeded 307,000 tons.

Ignoring the two drawbacks specified, the coal is of very high grade, as the following analyses and particulars will show, and has a calorific value better than that of the average Raniganj coal. The average composition of ten samples was found to be as follows:[56]

C: 75.9 per cent., H: 5.18, 0 and N: 12.42, S: 2.32, ash: 2.03 and water: 2.15.

The lowest or main seam in the Bottom colliery at Namdang gives: [57]

Moisture	2.59%
Ash (red) in dry coal	1.00%
Volatiles at 900° C. from dry coal	38.98%
Gross calorific value in B.t.u. per lb. of dry coal	14,700

[53] G. E. Hines, Trans. Inst. Min. Eng., Vol. 81, 466-467 (1931).

[54] R. R. Simpson, Rec. 34, 239 (1906).

[55] G. E. Harris, Trans. Manch. Geol. Soc. pt. 19, Vol. 26, 576-578 (1901).

[56] A. Kitt, Rec. 15, 61 (1882).

[57] G. E. Hines, Trans. Inst. Min. Eng. 81, 472-473 (1931).

Its ultimate composition has been found to be:

C	80.83 per cent.
H	5.42 „ „
N	0.95 „ „
S	1.25 „ „
O	10.55 „ „

In the Ladaigarh and Jaipur structures the Barails are exposed for a length of about 25 miles, on the other side of the Tipam hills. Here they have been raised and exposed by a reversed fault to the east of Jaipur, stretching southwards and south-westwards for several miles beyond the Disang. The Coal Measures, the uppermost part of which appears to be absent, exceed 1,000 feet in thickness near the Disang river, but diminish rapidly northwards according to Mr. Evans, the total thickness near Sarai Pung being only 150 feet. The coal is of somewhat lower grade than that of Namdang and varies greatly in hardness from place to place; seams in the south attain considerable thickness but are much thinner towards the north.[58] The beds cross the Safrai, Tichak, Tibai (Tiok), Tiru and Disang valleys. At the junction of the Chota Taukok with the Safrai there are seams rising to 15 feet; the five workable seams of this area aggregate nearly 74 feet.

The Coal Measures of the Nazira field, brought up again by similar faults and traversed by the Dikhu river a dozen miles or less to the southeast of the village of Nazira, form a narrow, highly inclined outcrop about 16 miles in length. There are many coal seams but most of them are too thin for commercial purposes.

North-eastwards there is a gap in the Coal Measure outcrop between the Tirap and the Namchik, due to a denuded embayment in the range. Coal seams occur in the Namchik and Namphuk rivers, and further east near Wintong and Phanla. In the Namchik 60 feet of coal have been measured within 360 feet of strata, the best seam being 26 feet thick; the quality is excellent but most of the coal of this area lies below water level.[59]

The Coal Measures with thin coal seams occur in the Miao Bum range and extend to the Dihing river where sandstones belonging to the formation give rise to a gorge well over 1,000 feet deep. The same stage carrying two seams of coal, 3 feet and 6 feet thick, is exposed also on the Burma side of the Patkoi, in the Nawng-yang Hka, below the lake of the same name.

The Coal Measures, perhaps capped by the Tipam rocks, occupy a long spur in the Manabhum range, extending out from the Miju Mishmi country into the plains, parallel to the Noa Dihing.[60]

In the Lushai hills, between Fort Lungleh and Teriat, some nodular dark grey sandstones have yielded marine or estuarine fossils, and

[58] R. R. Simpson, Rec. 34, 226 (1906).
[59] E. H. Pascoe, Rec. 41, 215 (1911).
[60] Gen. Rep. Rec. 32, 150 (1905).

are of a facies apparently the same as the fossiliferous sandstones overlying Nummulitic limestone in the Garo and Khasi Hills.[61]

The Assam Oilfields.—Numerous oil seepages in the Coal Measures, and in their equivalents in Lower Assam, have attracted considerable attention in the past. Within the Cachar boundary such seepages have been reported near Masimpur, and again eleven or twelve miles further west, in both cases on the Barak river. A third locality exhibiting oil indications exists thirteen or fourteen miles north of Badarpur, near the Larang river, while traces of oil are reported to have been seen at various spots in the Saraspur hills.[62] The Badarpur oilfield, situated on a small asymmetrical dome, has yielded disappointing results and was abandoned in 1933; the oil met with here was of an inferior quality and the wells showed a rapid decline.[63] The Surma valley and the Nasimpur area are still being tested for oil. In the Khasia Hills seepages are known near Chela and seven miles to the west in the vicinity of Khasimara, where boring has been tried;[64] fifteen miles further west, the Dhamalia valley also shows oil indications. On the southern margin of the Garo Hills similar indications are reported at Dholakhal in the Someswari valley.[65]

Proceeding north-eastwards from the Shillong plateau margin, we find springs of blue sulphurous mud oozing from a *pung* or "salt-lick" in the Meyongdisa stream, southeast of Gudu village, in the Mikir hills of Nowgong. Twenty miles S.S.E. of Jorhat, in the Disai (Disa) river is a petroleum seepage occurring in a strip of Coal Measures between two outcrops of Tipam sandstone. Two or three oil seepages occur in the Dikhu river where it traverses the Nazira coalfield, the structure of the latter being an anticlinal dome overfolded towards the northwest. Five or six miles further northeast are two other seepages in Coal Measure beds which are mapped as continuous in strike with those of Nazira but belong probably to a separate dome structure. Twenty-eight miles northeast of the seepages on the Dikhu is a small lenticular outcrop in the Tichak valley, 1½ miles long by 300-400 feet wide, of Coal Measures intercalated between the Tipams and the Disangs, its boundary with the latter being the great thrust fault. The beds carry several coal seams, one of them 12 feet thick; an oil seepage is mentioned by Mallet in the Tiok valley northeast of the Coal Measure outcrop, and another by Hayden two miles lower down the river.[66] Some 44 miles northeast of the Dikhu, several seepages of petroleum are to be found in the branches of a tributary of the Disang, southeast of Namrup railway station; some of the coal seams of this locality are impregnated with the oil. Other seepages are known between the Disang and the Dihing, and in the hills immediately northeast of Jaipur; five miles from the latter town an oil-sand crops out in a small stream.

[61] T. H. D. La Touche, Rec. 24, 98 (1891).
[62] E. H. Pascoe, Mem. 40, 310 (1914).
[63] Mineral productions. Rec. 70, 279 (1935).
[64] R. W. Palmer, Rec. 55, 165 (1923).
[65] E. H. Pascoe, Mem. 40, 311 (1914).
[66] H. H. Hayden, Rec. 40, 311-316 (1910).

Some 15 or 16 miles northeast of Jaipur is the Digboi oil-field, occupying an asymmetric dome and producing about 50 million gallons of crude oil annually. Exposures of country rock are scanty and obscure, and it is doubtful whether the Coal Measures actually reach the surface. It is thought by some that the sands which supply the oil belong to the Coal Measures and that the upper contact of this formation with the overlying Tipams may be an unconformity showing no perceptible angularity. In P. Evans' opinion, however, based on a prolonged study of Assam geology and supported by the evidence of heavy mineral contents, the beds in which the oil now lies belong to the Tipams or at any rate are of Tipam facies; should this be the case, it seems justifiable to assume that the oil has migrated up from deeper-lying Coal Measures.

Numerous natural seepages occur in the streams of the Namdang area, southeast of Digboi. The Namchik area contains many *pungs* or "salt-licks" from which gas issues in considerable volumes; small traces of petroleum also occur. Gas occurrences have been reported from the Maiobum area and from a locality 16-18 miles further E.N.E.

Summary of relationships between north and south Assam.—Reviewing the Barail series as a whole, we find on passing from Lower to Upper Assam, a change of facies, the transition occurring roughly between Nichu Guard and Cholimsen, where a sandstone with a remarkable concretionary structure, seen at Wokha and Mokokchung (Mokochaung), has been referred to the Naogaon Sandstone.[67] This change from southwest to northeast is accompanied by a marked increase in the coal content until a maximum is reached at Namdang-Ledo. As Evans remarks, beyond the Dimapur-Kohima road abundant thin seams make their appearance. Across the Dayang valley seams up to 10 or 12 feet are found, and are mined on a large scale at Nazira; from Nazira north-eastwards the increase is less and more gradual. The Coal Measures as such can be traced from Namdang south-westwards for a hundred miles, and from the same point E.N.E. 'wards along the northern front of the Patkoi hills for 40 miles or more.[68] Across their general strike, from southeast to northwest, the Barail series shows a decrease in argillaceous material and a general increase in the coarseness of its deposits, indications, as Mr. Evans remarks, of an approach to a shore-line. A decrease in argillaceous sediments on a smaller scale has also been detected from southwest to northeast. In marine fossils the Barails are singularly poor: a few specimens collected from the upper Coal Measures suggest to Mr. F. E. Eames an Oligocene age but afford no definite clue.

The Palæogeography of the Oligocene period will be considered at the end of chapter XXXI, which describes a formation in Burma which strides the Oligocene and Miocene.

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[67] H. H. Hayden, Rec. 40, 286 (1910).
[68] V. Ball & R. R. Simpson, Mem 41, 15-16 (1913).

CHAPTER XXXI.

TERTIARY (CONTINUED)—THE LOWER MIOCENE OF INDIA.

Western India: Classification and relationships; **Sind:** Character and distribution of the Gaj series; Gaj fauna of Sind, **Cutch, Kathiawar.** Relationships of the Gaj fauna. **Baluchistan. Surat and Broach. Ratnagiri. Travancore. Fresh-water facies of the Gaj:** Sind; The Bugti hills; **Northwest India and the Himalaya:** The Sulaiman area. **The Murree series:** Distribution; Kohat; Peshawar; Northern Punjab; Kashmir; Mandi State and the Simla foot-hills; Mode of accumulation of the Murree series and its equivalents; **Assam:** Basal unconformity; The Surma series. **Hill Tippera and Chittagong; Mayurbhanj; Puri; The Durgapur beds of the Damodar valley.**

WESTERN INDIA.

Classification and relationships.—The Miocene in western India is represented by the Gaj series together with a large but uncertain part of the succeeding Manchhar series. Equivalent to part of the Upper Manchhars is the lower part of the Makran series and this, known as the Talar stage, has been assigned to the Pontian and therefore forms a part of the Pliocene, if the Pontian be included in that series. The relationships of the Upper Tertiaries of western and northwestern India may be briefly tabulated as follows (opp. page).—

In this chapter it is proposed to consider the Gaj series of Sind, including outlying exposures in Cutch, Kathiawar, Surat, Broach, Ratnagiri and Travancore; the Murree series of northwest India; the Dagshai-Kasauli sequence in the Simla foot-hills and central Himalaya; the Surma series of Assam; and various more or less isolated formations exposed in Hill Tippera, Chittagong, Mayurbhanj, Puri, and the Damodar valley. The Kojak Shales of Baluchistan, whose stride includes the Gaj, have been already described.

SIND.

Character and distribution of the Gaj series.—Lithologically the Gaj series is frequently very similar to the Nari in western India. The largest exposure of the former is that which occupies the Mol and Maihar plateaux and many of the ridges east of the Hab river covering the greater part of the Karachi district and stretching northwards with a very irregular outline to a point due west of Hala; southwards it forms a low range of hills extending to Cape Monze west of Karachi city. In this large tract of the Gaj series, a large proportion is made up of pale limestones, lying almost horizontally and forming plateaux, 300-400 feet high, bounded by steep scarps rising from the low ground occupied by the Nari sandstones. East of Karachi the Gaj beds extend as far as Jungshahi where, with other Tertiary rocks, they disappear under the Indus alluvium. From the low hills east and northeast of Karachi the Gaj rocks have furnished

Relationship of the Upper Tertiaries of Western and North-Western India.

WEST INDIA.			NORTHWEST INDIA.		EUROPE.		JAVA.	PERSIA AND MESOPOTAMIA.
			Upper Siwalik.	Boulder Conglomerate.	Middle Pleistocene.	Pleistocene.	Trinil.	Upper Bakhtiari.
				(? Lower Karewas)	Cromerian.		Djetis.	
		Upper Manchhar.		Pinjor.	Villafranchian.	Pliocene.	Sonde.	
Makran Series.	Gwadar.			Tatrot.	Astian.			Lower Bakhtiari.
	Talar.		Middle Siwalik.	Dhok Pathan.	Pontian.		Odeng.	
K O J A K		Lower Manchhar.		Nagri.	Sarmatian.	Miocene.	Tji Lanang.	Upper Fars.
			Lower Siwalik.	Chinji.	Tortonian.			Middle Fars.
				Kamlial.	Helvetian.			
		Estuarine Passage beds.	Upper Murree.	Kasauli.	Upper Burdigalian.		Njalindung.	Lower Fars.
S H A L E S	Upper Gaj.	Bugti Bone Beds.	Lower Murree, with Fatehganj zone.	Dagshai.	Lower Burdigalian.			Euphrates or Asmari Limestone.
	Lower Gaj.				Aquitanian.		Rembang (Ramban).	
	Nari.							

the material of which the houses in the town are mostly built; the massive and well developed limestones of these hills reach as far as the coast. West of Cape Monze the small island of Churna is also built up of Gaj rocks.

Northwards several small outliers connect this southern outcrop with that of the type area which stretches from the vicinity of the Manchhar Lake northwards for over ninety miles in a discontinuous ridge along the eastern flank of the Kirthar range in Upper Sind. This conspicuous ridge owes its existence to the hard, dark brown limestone bands near the base of the Gaj formation, which resist denudation far more than the adjacent soft Nari sandstones, and rise in peaks of 1,000 or 1.500 feet or even more, escarped on the west and sloping to the east, the highest summit, Amru, being 2,700 feet above sea-level. This outcrop is traversed by the Gaj river which has given its name to the series and displays a superb section of 25,000 feet of strata ranging from Cretaceous to Manchhar, with the omission of the Ranikot, Laki and Lower Nari; it is the only stream which has cut its way completely through the Kirthar range.

Almost throughout Sind, the Gaj with a base of highly fossiliferous limestones and calcareous beds, more or less shaly and stratified, overlies the softer shales and sandstones of the Nari. The limestone bands, although more conspicuous, are subordinate to the other elements of the series, the greater part of which is composed of sandy shales, gypseous clays and, towards the base, sandstones. Massive gypsum is sometimes seen. Many bands of the limestone are very constant in stratigraphical position and traceable for long distances. Most of the limestones are of a dark brown or yellow colour, some of them containing echinoderms in large numbers; one of the bands, however, is white and abounds in corals and small foraminifera. One of the limestones near the base of the Gaj has been found to yield traces of oil in a boring at Drigh Road near Karachi.[1]

The Gaj beds at the Gaj river are very nearly 1,500 feet thick, but are less developed in the more northern parts of the Kirthar range; west of Larkana they are not much more than half the figure named, but the beds are here nearly vertical and may have suffered compression. To the east of the Laki range in Lower Sind, the Gaj series, like the Nari, disappears entirely or is represented by a few pebble beds or by a thin oyster bed containing a characteristic Gaj fossil, *Ostraea angulata* and *Pecten subcroneus*, being found interstratified with the uppermost Nari sandstones.[2] A doubtful case of actual unconformity is recorded a few miles west of Sehwan. A few miles to the south of this town, on the western side of the Bhagotoro hills, there is clear evidence of a local break, the Gaj in the form of variegated shales, clays and sandstones, many of them richly

[1] H. Crookshank, Rec. 60, 157-158 (1927).

[2] W. T. Blanford, Mem. 17, 55-56 (1879); P. M. Duncan, Pal. Ind., Ser. 7 & 14, Vol. 1, Mem. 2, 4, (1880).

tinted with brown and red, resting unconformably on the denuded edges of Lower Nari brown limestones and shales, and overlapping them on to the Kirthar limestone; it is itself overlapped by Manchhar beds in the immediate neighbourhood. In the majority of cases not only is there a perfectly gradual passage up from the Nari to the Gaj, but the faunistic differences between the two formations are far less marked than they are between the other Tertiary series, and the Nari is much more closely connected with the Gaj than it is with the Kirthar.

In the Kirthar range and the Karachi region the uppermost portion of the Gaj becomes more argillaceous in character, consisting chiefly of variegated red and olive clays, white gypsum and grey sandstones, and containing fossils, nearly all of which have allies in the estuaries of the present day, such as: *Turritella* (*Torculoidea*) *angulata* Sow., species of *Ostraea* and *Placuna* including *Ostraea angulata* Sow., *Corbula trigonalis, Lucina* (*Diplodonta*) *incerta, Arca larkanensis, Vicarya verneuili* and the crab, *Typilobus*; *Arca granosa,* a recent representative of *A. larkanensis* is one of the commonest and most typical of the modern Indian estuarine mollusca.[3] These sediments form as it were estuarine passage beds up into the Manchhar, and may be grouped as a topmost arenaceous phase of the Gaj, into which the calcareous beds of the series pass upwards.[4] In the Karachi region the ordinary fresh-water Manchhar sequence is not found but its place is partly taken by some basal beds which may be regarded as an estuarine facies of the lowest Manchhar horizons, and partly by the upper portion of the Kojak series and the Makran series. In the Kirthar range the marine Makran stage is not recognisable as such but is replaced by part of the fresh-water Manchhar series.

Gaj fauna of Sind.—In the Gaj are two closely related though distinct faunas, a lower and an upper. This further subdivision has not been made on the map, and in many cases assemblages of fossils cannot be definitely recognised as belonging to either the lower or upper stage; the fauna of each region will, therefore, be given as a whole, with indications, when known, as to the more precise provenance of some of the forms.

As in the case of the Nari, the Gaj rocks are often crowded with large lepidocyclines.[5] The Gaj forms belong to the group *Lepidocyclina marginata,* with well developed pillars and a megalosphere only partially surrounded by the second cell; the largest specimens have a diameter of 45 mm. The lepidocyclines are accompanied by

[3] P. M. Duncan and P. Sladen, Pal. Ind. Ser. 7 & 14, Vol. 1, pt. 3, Fasc. 5, 274 (1885).

[4] Vredenburg describes them as passage beds from the Gaj to the Makran (Hinglaj), which is not represented here, but this emendation is scarcely tenable if the Makran series be equated with the Dhok Pathan-Tatrot-Pinjor stages of the Siwalik; between the Gaj and the Dhok Pathan come the three stages, Kamlial, Chinji and Nagri.

[5] E. Vredenburg, Rec. 34, 267 (1906).

Operculina, Rotalia and other foraminifera; one lenticular and very nummulitiform species of *Operculina* is the form described by Carter under the name of "*Nummulites makullaensis*".[6] In places great masses of coral limestone are seen to be made up of the casts of *Stephanocoenia maxima.* The following fossils have been found in the Gaj of Sind; those found also in Cutch are marked (*c*):

FORAMINIFERA.

Operculina makullaensis (Cart.),
Lepidocyclina blanfordi Nutt. (of the same type as Carter's "*Orbitolites* mantelli"),[7] W.L.F. Nuttall.

ALCYONARIA.[8]

Caryophyllia gajensis Dunc.,
Trochocyathus gajensis Dunc.,
Stylophora confusa Dunc.,
Stylophora minuta, var., Dunc.,
Stephanocœnia maxima Dunc.,
Antillia plana Dunc.,
Antillia indica Dunc.,
Montlivaltia jacquemonti Haime.
Dasyphyllia sp.,
Leptomussa rugosa Dunc.,
Calamophyllia elongata Dunc.,
Leptoria concentrica Dunc.,
Monticulastraea insignis Dunc.

ACTINOZOA.

Oculina halensis Dunc.,
Phyllocoenia conferta Dunc.,
Phyllocoenia lucasana M. Edw. & H.,
Astrocoenia caillaudi M. Edw. & H.,
Montlivalitia brevis Dunc.,
Antillia dentata Dunc.,
Antillia ponderosa (M. Edw. & H.),
Hydnophora rudis Dunc.,
Hydnophora plana Dunc.,
Hydnophora hemisphaerica Dunc.,
Trochoseris apertu Dunc.,
Cyathoseris valmondoisiaca var., M. Edw. & H.,
Pachyseris rugosa M. Edw. & H.,
Agaricia agaricites M. Edw. & H.,
Porites incrustans M. Edw. & H.

Several other species of Sind corals have been described but, the localities being unknown or uncertain, they have been omitted (see Pal. Ind., Ser. 7 and 14, Vol. 1, 105 (1880).

From the Miocene of Kathiawar are recorded: *Cidaris depressa* Dunc. & Sl., *C. granulata* Dunc. and Sl., *Temnechinus. costatus* Dunc. & Sl., *T. tuberculosus* d'Arch., *Grammechinus regularis* Dunc. & Sl., *Eupatagus Patellaris* d'Arch & H. (also from Cutch Miocene).

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[6] H. J. Carter, Ann. Mag. Nat. Hist., Vol. 8, 375 (1861).

[7] W. L. F. Nuttall, Ann. Mag. Nat. Hist. Ser. 9, Vol. 17, 330 (1926).

[8] P. M. Duncan, unrevised Pal. Ind. Ser. 7 and 14, Vol. 1, pt. 2, p. 81 (1880). To these may be added with some confidence the following from the neighbourhood of Karachi and therefore probably from the Gaj: (P. M. Duncan, Ann. Mag. Nat. Hist., Third Series, Vol. 13, 296-297, (1864).

Monticulastraea solidior Dunc.,
Monticulastraea inœqualis Dunc.,
Monticulastraea elongata Dunc.,
Heliastraea sindiana Dunc.,
Heliastraea digitata Dunc.,
Heliastraea anomala Dunc.,
Brachyphyllia indica Dunc.[9],
Plesiastraea costata Dunc.,
Plesiastraea decipiens Dunc.,
Plesiastraea pedunculata Dunc.,
D'Achiardia densa Dunc.,
D'Achiardia lobata Dunc.,
Latimaeandra parvula Dunc.,
Latimaeandra reussi Dunc.,
Latimaeandra gajensis Dunc.,
Prionastraea gajensis Dunc.,
Prionastraea fungiformis Dunc.,
Cladocora haimei Dunc.,
Echinopora miocenica Dunc..
Echinopora maxima Dunc.

ACTINOZOA.

Pachyseris affinis Dunc.,
Pachyseris exarata Dunc.,
Cycloseris magnifica Dunc.,
Agaricia danae Dunc.,
Madrepora sp.,
Turbinaria sitaensis Dunc.,
Astraeopora hemisphaerica Dunc.,
Isis danae Dunc., and var.,
Isis elongata Dunc.,
Isis compressa Dunc.

ECHINOIDEA.[10]

Cidaris opipara Dunc. & Sl.,
Cidaris excelsa Dunc. & Sl.,
(c) *Caelopleurus forbesi* (d'Arch. & H.; found also in the Miocene of Kathiawar),
Caelopleurus sindensis Dunc. & Sl.,
(c) *Temnechinus rousseaui* d'Arch. & H.; (found also in the Miocene of Kathiawar),
Temnechinus affinis Dunc. & Sl. (found also in the Miocene of Kathiawar),
Temnechinus stellulatus Dunc. & Sl.,
Temnechinus gajensis Dunc. & Sl.,
Lepidopleurus hemisphaaericus Dunc. & Sl.,
Lepidopleurus granulatus Dunc. & Sl.,
Hipponoe proavia Dunc. & Sl.,
Hipponoe antiqua Dunc. & Sl.,
Echinus subcrenatus Dunc. & Sl.,
Clypeaster profundus (d'Arch.) Dunc. & Sl.,
Clypeaster pulvinatus Dunc. & Sl.,
Clypeaster pelviformis Dunc. & Sl.,
Clypeaster complanatus Dunc. & Sl.,
Clypeaster depressus Sow. (also from the Miocene of Kathiawar),
Echinodiscus desori Dunc. & Sl., and var.,
Echinodiscus placenta Dunc. & Sl.,
Echinodiscus ellipticus Dunc. & Sl.,

[9] Gen. Rep. Rec. 62, 22 (1929).
[10] P. M. Duncan and P. Sladen, Pal. Ind. Ser. 7 and 14, Vol. 1, pt. 3, Fasc. 5, 278-279 (1885).

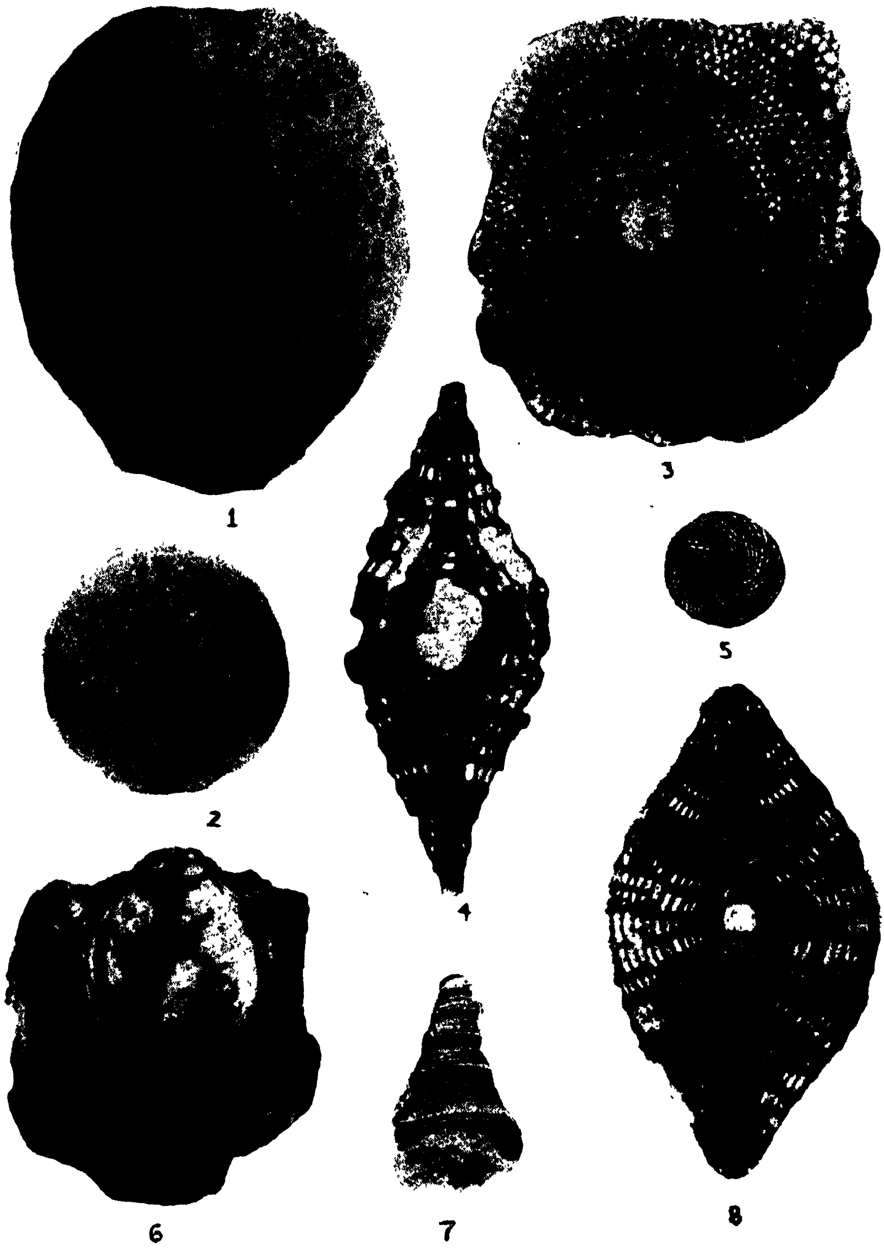
Echinodiscus elongatus Dunc. & Sl.,
Echinolampas jacquemonti d'Arch. & H. (typical),
Echinolampas spheroidalis ? d'Arch.,
Schizaster granti Dunc. & Sl. (also from the Miocene of Kathiawar),
Schizaster sufflatus Dunc. & Sl.,
Breynia carinata d'Arch. (characteristic and abundant) (also from the Miocene of Kathiawar),
Brissus sp.

LAMELLIBRANCHIATA.[11]

Arca submultiformis Vred. (Upper Gaj; abundant in the Miocene of Burma; very close to the *A. multiformis* Mart. of the Java Miocene),
Arca larkanensis d'Arch. (Upper Gaj),
(c) *Arca radiata* Sow. (Upper Gaj; found also in the Miocene of Burma),
(c) *Arca peethensis* d'Arch. (found in the Miocene of Burma),
Arca subfiligrana d'Arch. & H.,
(c) *Arca semitorta* Lam.,
Glycimeris (Pectunculus) sindiensis (Lower Gaj),
Glycimeris (Pectunculus) lima d'Arch. & H. (stratigraphical provenance uncertain),
Nucula studeri d'Arch. (Upper Gaj),
Placuna (Indoplacuna) sindiensis Vred. (Upper Gaj),
(c) *Ostraea angulata* Sow. (typical).
(c) *Ostraea latimarginata* Vred. (Upper Gaj; also in Burma and Persia),
Ostraea gajensis Vred. (Upper Gaj; also in the Miocene of Kathiawar and of Burma),
(c) *Ostraea imbricata* Lam. (Upper Gaj),
(c) *Ostraea gingensis* (Schloth.),
(c) *Ostraea lingua* Sow. (also from the transition beds at the top; very close to the living *O. talienwahnensis* Crosse, and to *O. rostralis* Lam. found in European Atlantic estuaries today),
Ostraea vestita Fuchs (Upper Gaj, including the transition beds),
Ostraea folium Gmel.,
(c) *Pecten (Amussiopecten) labadyei* d'Arch. & H.,
(c) *Pecten (Amussium) subcorneus* d'Arch. & H.,
(c) *Pecten (Aequipecten) scabrellus* Lam.,
(c) *Chlamys feddeni* Vred. (Lower Gaj),
(c) *Chlamys articulatus* Sow.,
(c) *Chlamys senatorius* Gmel. var. *soomrowensis* Sow. (species also found in the Asmari limestone and Fars of Persia),
(c) *Cardita muricata* Sow. (now living in the Pacific Ocean).
Lucina (Linga) columbella Lam. (Upper Gaj),
Diplodonta incerta d'Arch. (probably Upper Gaj),
(c) *Cardium (Discors) triforme* Sow. (European species),
Cardium (Trachycardium) greenoughi d'Arch. & H.,
Cardium picteti,[12]
(c) *Dosinia pseudoargus* (d'Arch. & H.) (very close to, if not identical with the living *D. exasperata*),
Cytherea (Caryatis) pratti (d'Arch. & H.) (stratigraphical provenance uncertain),
(c) *Venus (Omphaloclathum) puerpera* Linn., var. *granosa* Sow.,
(c) *Venus (Clementia) papyracea* Gray (also in the Asmari and Fars of Persia),
(c) ***Tapes (Callistotapes) virgatus*** (Sow.) (found in the Oligocene of N. Italy),

[11] E. Vredenburg, Mem. 50, pt. 2 (1928).

[12] L. R. Cox, Trans. Roy. Soc. Edin, Vol. 57, p. 83. (1934). Preserved as a cast in a coarse sandstone matrix identical with that containing types of *Venus subaglaurae* d'Arch and H a Miocene form.



LOWER MIOCENE FOSSILS

1. *Breynia carinata* d'Arch. & Haime (X1). 2. *Echinolampus jacquemonti* d'Arch. & Haime (X1) 3. *Lepidocyclina tournoueri* Lem. & Douv., Horizontal Section (X18). 4 *Lepidocyclina tournoueri* Lem. & Douv , Vertical Section (X22.1/2). 5. *Orbiculina malabarica* (Carter) (X1) 6 *Ostraea latimarginata* Vred. Internal view (X1). 7. *Turritella angulata* Sow (X1) 8. *Lepidocyclina sumatrensis* (Brady) (X18).

G S I., Calcutta

(c) *Tellina exarata* Sow.,
(c) *Corbula trigonalis* Sow.,
Pholadomya puschi Goldf. (stratigraphical provenance uncertain ; a European form, very frequent in the Oligocene, ranging to the base of the Vindobonian).

GASTROPODA

Surcula tuberculata (Gray), var. *voysevi.* (d'Arch. & H.),
Conns (Leptoconus) fasciatus Mart. (found in Java),
(c) *Olivancillaria (Agaronia) nebulosa* Lam., var. *pupa* Sow. (found also in the Oligocene and Miocene of Burma ; species living off Bombay and Karachi),
(c) *Athleta (Volutospina) dentata* Sow., var. *sykesi* d'Arch.,
(c) *Lyria jugosa* (Sow.),
Mitra (Cancilla) rembangensis Mart. (found also in Burma and Java),
Turbinella affinis Sow. (Lower Gaj),
Turbinella premekranica Vred. (Upper Gaj).
(c) *Melongena lainei* (de Bast.) (characteristic Miocene form in Europe ; close to *M. gigas* Mast. from the Miocene of Java),
Melongena galeodes Lam., var. *sindiensis* Vred. (living and abundant in eastern seas),
Metula martini Vred.,
(c) *Tritonidea (Cantharus) bucklandi* (d'Arch.) (found also in Burma ; very close to two living species, *Tr. erythrostoma* (Reeve) and *Tr. tranquebarica* Mart.),
Nassa (Telasco) falconeri (d'Arch. & H.) (very close to *N. verbeeki* Mart. from the Pliocene of Java and Karikal),
Nassa (Zeuxix ?) cautleyi (d'Arch. & H.),
Nassa (Hima) vicaryi (d'Arch), (very close to the living *N. pagoda* Reeve).
Murex (Haustellum) tchihatcheffi d'Arch. & H.,
Murex (Acupurpura) verbeeki Mart.,
(c) *Hindsia granosa* (Sow.),
Ranella (Apollon) morrisi d'Arch. & H ,
Cassidaria desori d'Arch. & H.,
(c) *Cypraea prunum* Sow., var. *nasuta* Sow. (also in the Kama stage of Burma),
Cypraea (Bernayia) subexcisa Braun (also in the Pegu of Burma and Oligocene of N. Italy),
Cypraea (Bernayia) humerosa Sow.,
Strombus sedanensis Mart (also found in the Lower Miocene of Java),
(c) *Strombus (Gallinula) columba* Lam.,
(c) *Terebellum subulatum* Lam., var. *obtusum* Sow ,
Cerithium (Vertagus) erectum Mart. (a Java form),
Cerithium (Ptychocerithium) archiaci Vred.,
Potamides (Tympanotomus) pseudodiaboli Vred.,
(c) *Potamides (Telescopium) charpentieri* de Bast.,
Potamides (Terebralia) bidentata Defr., var. (species found in Europe),
Potamides (Pyrazus) protebeninus Vred.,
Potamides (Cerithidea) preangerensis Mart. (a Java form),
Potamides (Cerithidea) sindiensis Vred.,
(c) *Turritella (Torculoidea) pseudobandongensis* Vred. (very close to the Javanese *T. bandongensis* Mart.),
Turritella (Torculoidella) angulata Sow.,
Protoma sindiense Vred.,
(c) *Solarium affine* Sow. (an ancestor of *S. maximum* of the present Indian seas),
Torinia euomphalides (d'Arch. & H.) (stratigraphical provenance uncertain),
Scalaria (Scala ; Cirsotrema) subtenuilamella d'Arch. & H.,
(c) *Trochus (Tectus) loryi* d'Arch. & H. (Lower Gaj),
Trochus (Thalotia ?) martinsi (d'Arch.) (provenance stratigraphically uncertain).

CEPHALOPODA.

Aturia aturi de Bast.? (Lower Gaj).

MAMMALIA.

Rhinoceros sivalensis Falc. & Cautl., var. *gajensis* Lyd.[13]

CUTCH.

Separated from the Tertiary exposure in Sind by the Indus alluvial tract, some 90 miles across, are the Tertiary rocks of Cutch, of which the group originally described by Wynne as the " Argillaceous Group, E " corresponds to the Gaj. This formation is the best developed of the Tertiary subdivisions in Cutch, and forms a highly fossiliferous belt covering the central parts and western coast of the main island. In the west these Miocene beds crop out around the exposures of Nari and Eocene and are overlapped by younger Tertiary sediments ; further east, *i.e.*, in the interior portion of the island they rest upon the " Sub-Nummulitic group ".

The base of the Gaj series in Cutch is made up of sandstones with a few nodular, marly and ferruginous bands often containing *Turritella* (*Torculoidea*), *Venus* (*Omphaloclathrum*) *puerpera* Linn., var. *granosa* Sow. (the equivalent of *V. aglaurae* Brongn.) and *Corbula*. Above the sandy beds come marly limestones and shales ; these are followed by calcareous grits, and these again by a considerable thickness of shales, clays and marls. The most fossiliferous beds are the marly limestones and shales.[14]

The Gaj fauna of Cutch has never been completely examined, partly owing to some confusion between the collections of fossils from the different series of the Tertiary.[15] Forms found in Cutch as well as in Sind have been denoted in the preceding lists by the letter (c) ; the following, derived from Duncan's determinations of the echinoids and Vredenburg's identifications of the mollusca, are additional species, *i.e.*, Gaj species found in Cutch but not as yet reported from Sind:[16]

ECHINOIDEA.[17]

Cidaris halaensis d'Arch. & H.,
Goniocidaris affinis Dunc. & Sl.,
Clypeaster waageni Dunc. & Sl..
Clypeaster goirensis Dunc. & Sl.,
Echinolampas indica Dunc. & Sl.,
Echinolampas wynnei Dunc. & Sl.,
Moira antiqua Dunc. & Sl ,
Troschelia tuberculata Dunc. & Sl.,
Eupatagus (vel *Euspatangus*) *patellaris* d'Arch. & H. (an exclusively Gaj species),
Schizaster granti Dunc. & Sl. (stratigraphical provenance uncertain ; but found in Gaj of Sind).

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[13] Pal. Ind. Ser. 10, Vol. 2, No. 1, 40 (1818-1884).
[14] Mem. 9, 48 (1872).
[15] C. W. Grant, Trans. Geol. Soc. 2nd Ser. 5, 800 (1840).
[16] Pal. Ind. Ser. 7 and 14, pt. 4, 6 (1885), Mem. 50 (1925-1928).
[17] Wrongly labelled " Arenaceous Group "; the echinoids may need revision.

LAMELLIBRANCHIATA.

Ostraea (Pycnodonta) brongniarti (Braun),[18]
Arca feddeni Vred. (=*A. trapeziformis* Mart. from Java),
Nucula cancellata Vred.,
Gryphaea (Pycnodonta) brongniarti Bronn. (European form),
Pecten (Amussiopecten) placenta Fuchs (also found in Burma),
Cardita (Venericardia) pseudonodulosa Vred. (close to *C. nodulosa* Reeve, now living in the Atlantic and Mediterranean),
Cytherea (Callista) pseudoumbonella Vred.,
Cytherea (Amiantis) incrassata (Sow.) (found in the Oligocene of Paris),
Corbula tunicosulcata Vred.

GASTROPODA.

Scaphander javanus Mart. (Java),
Atys protocylindrica Vred. (a small form of the living *A. cylindrica* Helb.),
Terebra (Myurella) reticulata Sow. (the equivalent of Martin's *T. indica* from the Miocene of Java, and Deshayes' *T. Lima* now living in eastern seas),
Terebra (Myurella) kachhensis Vred. (close to *T. reticulata*),
Pleurotoma ickei Mart. (from the Miocene of Java and the Pegu of Burma),
Pleurotoma (Hemipleurotoma) bonneti Cossm. (found also in Burma and Karikal),
Pleurotoma (Gemmula) congener E. A. Smith, var. *mekranica* Vred. (living in the Bay of Bengal and Arabian Sea at depths of 120—400 fathoms, and the equivalent of Martin's *Pl. coronifera* from the Miocene of Java),
Drillia (Crassispira) kachhensis Vred. (very close to *Dr. protointerrupta* now from the Pegu of Burma),
Conus (Leptoconus) marginatus Sow.,
Conus (Lithoconus) odengensis Mart. (common in both Java and Burma),
Conus (Lithoconus) brevis Sow.,
Oliva (Strephona) australis Ducl., var. *indica* Vred. (Another variety found in Java ; the species living in Australia and New Guinea),
Mitra chinensis Gray, var. *subscrobiculata* d'Orb., (found also in the Garo Hills ; species living),
Mitra (Chrysame) sowerbyi d'Orb.,
Fasciolaria (Pleuroploca) ? laeviuscula (Sow.),
Melongena cornuta Agass. (characteristic Miocene form in Europe),
Siphonalia (Kelletia) nodulosa (Sow.) (very close to *S. tjibaliungensis* Mart. from Java),
Nassa (Hebra) bonneti Cossm., var. *kachhensis* Vred.,
Muricopsis exhexagonus Vred.,
Persona (Distortrix) reticulata (Linn.) cum var. *subclathrata* d'Orb. et *metableta* Cossm. (species in the Oligocene and Miocene of Burma, the Upper Miocene and Pliocene of Java, and the Pliocene of Karikal),
Ranella (Biplex) bufo Sow. (very close to *R. pulchra* Gray, living in eastern seas),
Cassidea mamillaris Gratel, var. *pedemontana* Sacco (from the Miocene of Piedmont),
Cassidea (Bezoardica) sculpta Sow. (very close to *B. strigata* (Gmel.), living in the Pacific),
Pyrula kachhensis Vred. (very close to *P. pamotanensis* Mart. from Java),
Cypraea prunum Sow. (also the variety, *nasuta* Sow),
Rimella subrimosa d'Orb.,
Cerithium (Vertagus) kachhense Vred.,
Cerithium (Ptychocerithium) pseudocorrugatum d'Orb.,
Cerithium (Ptychocerithium) rude Sow. (exclusively characteristic of the Gaj),

[18] L. R. Cox, Trans. Roy. Soc. Edin., Vol. 57, 34 (1934).

Cerithium (*Vulgocerithium*) *vulgatum* Brug. (Locality uncertain but probably Upper Gaj),
Rostellaria protofusus Vred. (very close to the recent *R. rectirostris* Lam.),
Turritella assimilis Sow.,
Turritella heberti d'Arch. & H.,
Mathilda quadricarinata Brocchi (abundant in the Miocene of N. Italy, and living in the Mediterranean),
Siliquaria granti Sow.,
Calyptraea chinensis (Linn.) (Recent and almost cosmopolitan),
Natica obscura Sow.,
Natica (*Polinices*) *powisiana* Recl. (Locality unknown, but probably Gaj),
Ampullonatica angulifera Sow.,
Ampullina (*Cernina*) *callosa* Sow.,
Scalaria (*Scala*; *Clathrus*) *gajensis* Vred.,
Trochus (*Tectus*) *cognatus* Sow. (close to *Tr. lucasanus* Brongn. from the Oligocene of Castel-Gomberto).

KATHIAWAR.

On the other side of the Gulf of Cutch, at the western end of the Kathiawar peninsula, the Gaj and some younger Tertiaries are exposed and occur as small disconnected outcrops in the fringe of coastal alluvium round the southern limits of the Trap area. These beds are almost horizontal and are much obscured by recent deposits and cultivation; in the absence of any deeply cut sections no general succession has been made out, but the aggregate thickness of the Tertiaries must amount to several hundred feet.[19] In northeast Kathiawar and the adjoining Ahmedabad district gas occurs in the Gaj beds, as it does on the other side of the Gulf of Cambay; a few boreholes have been sunk in the hope of striking oil but with no marked success.[20] At the western end of the peninsula the Gaj beds are overlain by a younger series described as the Dwarka beds. At the eastern end the patch of Tertiaries to the south of Bhawanagar (Bhavnagar), although mapped by Fedden as Gaj, is probably younger and may be Makran or Manchhar: the little island of Piram ("Perim", also mapped as Gaj) is made up of Manchhar rocks. Two or three of the smaller Tertiary occurrences southwest of the Bhawanagar tract may also be post-Gaj in age.[21] The following fossils are reported to have come from the Gaj of Kathiawar:

BRYOZOA (from north of Jafarabad).

Escharia halaensis,
Discoflustrella vandenheckei.

ALCYONARIA.

Cladocora ? sp.,
Pachyseris murchisoni Haime,
Trochocyathus sp.
Cyclolites sp.,

[19] F. Fedden, Mem. 21, 108 (1884).
[20] Gen. Rep. Rec. 71, 47 (1936).
[21] Near Dongar the beds are said to have yielded the coral *Stylocoenia*, *Vicaryi*, *Haime*; this, however, is a Ranikot form and its reported occurrence may be a mistake due to the confusion which seems to have characterised the fossil collections from Cutch.

ECHINOIDEA.

Cidaris depressa Dunc. & Sl., ..
Cidaris granulata Dunc. & Sl.,
Cidaris halaensis d'Arch. & H.,
Goniocidaris affinis Dunc. & Sl.,
Coelopleurus forbesi d'Arch. & H. (from the younger Tertiaries of the eastern outcrop; whether this form is found also in the true Gaj is uncertain),
Temnechinus rousseaui d'Arch. & H.,
Temnechinus costatus d'Arch.,
Temnechinus tuberculosus d'Arch. & H.,
Temnechinus affinis Dunc. & Sl.,
Grammechinus regularis Dunc. & Sl.,
Clypeaster depressus C. Sow.,
Clypeaster goirensis Dunc. & Sl.,
Clypeaster waageni Dunc. & Sl.,
Echinodiscus desori Dunc & Sl.,
Echinolampas indica Dunc. & Sl.,
Echinolampas jacquemonti d'Arch. & H,
Echinolampas spheroidalis d'Arch.,
Echinolampas wynnei Dunc. & Sl.,
Schizaster sp.,
Brissopsis sp.,
Schizaster granti Dunc. & Sl.,
Moira antiqua Dunc & Sl,
Breynia carinata d'Arch. & Sl,
Trosche'ia tuberculata Dunc & Sl.,
Eupatagus patellaris d'Arch. & H.

LAMELLIBRANCHIATA.

Arca radiata Sow. (originally identified as *A. hybrida* Sow.),
Arca semitorta Lam. (originally identified as *A. tortuosa* Lam var. *kurrachiensis* d'Arch.),
Arca larkanensis d'Arch.,
Arca peethensis d'Arch.,
Ostraea gajensis Vred.,
Ostraea angulata Sow. (originally identified as *O. multicostata* Desh.),
Ostraea latimarginata Vred.,
Glycimeris (Pectunculus) sindiensis Vred. (originally identified as *P. pecten* Sow.),
Nucula trigonalis,
Placuna probably *(Indoplacuna) sindiensis* Vred.,
Pecten (Amussium)[22] *subcorneus* d'Arch. & H. (originally identified as *P. corneus* Sow.),
Chlamys articulatus Sow. (originally identified as P. *bouei* d'Arch., var.).
Chlamys articulatus senatorius Gmel. var. *soomrowensis* Sow. (originally identified as *Pecten favrei* d'Arch.) and *P. soomrowensis* Sow.),
Cardium (Discors) triforme Sow.,
Cardium picteti, var.? d'Arch. & H.,
Cardium brongniarti ? d'Arch.,
Dosinia pseudoargus (d'Arch. & H.),
Venus (Omphaloclathrum) puerpera Linn., var. *granosa* Sow. (originally *V. granosa* Sow. and *V. cancellata* Sow.),

[22] H. C. Das Gupta also records *Pecten (Amussium) hathabiensis* Das-G, *Chlamys tauroperstriata*, Sacco, var. *Spinosa* Das-G., *Chl. middlemissi* Das-G. (J. A. S. B. New Ser. 19, 71-84, (1923) and the common India edible crab, *Scylia serrata*, Forskal J. A. S. B. New Ser. 20, 239 (1924)), but the specimens were collected from the doubtful beds exposed to the south of Bhawanagar.

Venus (Clementia) papyracea Gray (originally *V. nonscripta* Sow. and *Astarte hydrabadensis* d'Arch. & H.),
Tapes (Callistotapes) virgatus Sow. (originally *Pullastra virgata* Sow. or *Venus subvirgata* d'Orb.),
Tellina exarata Sow.,
Cyprina transversa (?) d'Arch. & H.,
Spondylus rouaulti d'Arch.

GASTROPODA.

Lyria jugosa Sow. (originally *Voluta edwardsi* var. d'Arch.),
Turbinella affinis Sow. (Lower Gaj),
Hindsia granosa (Sow.), (Originally *Ranella viperina* d'Arch. & H.),
Buccinum fittoni d'Arch. & H. (unrevised),
Cassis sp.,
Cypraea prunum Sow., var. *nasuta* Sow.,
Cypraea (Bernayia) humerosa Sow.,
Strombus sedanensis Mart, (*Originally S. fortisi* (?) Brongn.),
Strombus gigas (unrevised),
Eburna sp.,
Cerithium (Ptychocerithium) rude Sow.,
Turritella angulata Sow.,
Turritella vitulata (?) Ad. & Reeve (originally *T. vittata*),
Turritella subfasciata d'Arch. & H., (unrevised),
Ampullina (Cernina) callosa Sow. (Originally *Natica callosa* Sow.),
Trochus (Tectus) loryi d'Arch. & H.,
Trochus (Tectus) cognatus Sow.,
Trochus cumulans Brongn. (unrevised),
Cerithium (Ptychocerithium) pseudocorrugatum d'Orb. (originally *C. corrupatum* Sow.),
Ampullospira (Euspirocrommium) oweni d'Arch. & H. (originally *Phasianella owen* (?) d'Arch & H.).

CEPHALOPODA.

Sepia sp.,
Nautilus sp.,
Scylla serrata Forsk. (the common edible crab if India).[23]
A coral zone occurs not far above the base of the series.

Relationships of the Gaj fauna.—The corals and echinoids of the Gaj fauna are characterised by an almost complete disappearance of Eocene species. The Gaj corals are also very different from those of the Nari, the genera, *Cladocora* and *Echinopora* appearing for the first time; the presence of the genera, *Madrepora, Heliastraea* and *Porites* points to shallow-water conditions. Echinoids are numerous, the genus, *Echinodiscus* being new. On the other hand, there are many molluscan species common to the Nari and Gaj. The leading Gaj fossils are: *Ostraea latimarginata* Vred., *Breynia carinata, Echinolampas jacquemonti,* and *Lepidocyclina* cf. *marginata*[24]; exclusively characteristic of the series are *Eupatagus patellaris* and *Cerithium rude*. The proportion of European species in the Gaj is much smaller than that in the Nari, and the ocean connection between western India and Europe, which was perhaps completely interrupted in Upper Oligocene times, seems to have been re-established only

[23] The common edible crab of India J. A. S. B. New Ser, Vol. 20, 239 (1924).
[24] Pal. Ind., New Ser. Vol. 3, Pl. 7 (1909).

imperfectly during the Lower Miocene. The Lower and Upper Gaj approximate closely to the Aquitanian and Lower Burdigalian respectively. Of the Siphonostomatous gastropods in the Gaj, about 19 per cent. (10 out of 52) are living forms.[25]

BALUCHISTAN.

In southern Baluchistan, the thick Tertiary flysch known as the Kojak Shales, already described (p. 1620), very probably includes the Gaj as well as the Nari, and is succeeded by the white sandstones of the Pliocene Makran series (Hinglaj). This flysch extends into the Persian Makran and is believed to be of Mio-Pliocene age in the coastal parts of this region.

SURAT AND BROACH.

On the other side of the Gulf of Cambay, the two outcrops of Tertiary beds between the mouths of the Narbada and Tapti are made up of a lower group which has already been described under the heading of Eocene (p. 1520), and an upper which is now to be considered. The two outcrops, as explained, are separated from each other by the Kim river and its alluvium. Like the Eocene beds upon which they lie, the younger Tertiaries of this area consist of loose conglomerates, grits, and ferruginous sandstones which are often calcareous, overlain by sandy or calcareous clays. Thin bands of limestone also occur, but are either unfossiliferous or contain fossils differing from those in the Eocene group below.[26] The younger beds are poorly exposed in the Tapti and Kim rivers but are well seen around Kandh, Jhagadia and Limet, and in the small stream flowing past Damlai and Ratanpur, to the east of Broach city.[27] In the conglomerates trappean pebbles. so common in the Eocene conglomerates of the lower group, are either very rare or entirely absent. Their place is taken by pebbles of agate and other forms of quartz, derived from the Trap, or by rolled fragments of limestone and calcareous sandstone derived apparently from the older subjacent group ; this is most conspicuously the case at Limet, Hirapur and Kandh. In the stream passing Damlai and Ratanpur the quartzose variety of pebble is the most abundant, and from the vicinity of Ratanpur come the agates and carnelians which have from time immemorial suplied the lapidaries of Cambay. As in the lower group, the clays towards the surface become more or less ferruginous, with red, yellow and purple tints, and are in places lateritised ; they are well seen in the Damlai-Ratanpur area.

As a rule the dip is steady and quite low, the prevailing direction being northwest or west, as it is in the underlying beds. The thickness of the whole Tertiary sequence exposed near Ratanpur appears to be between 4,000 and 5,000 feet, but this estimate is based on imperfect exposures, and if, as appears possible, the lower beds are

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[25] E. W. Vredenburg, Rec. 53, 337 (1921).
[26] Rec. 37, 175 (1908).
[27] W. T. Blanford, Rec. 5, 94 (1872).

overlapped, the whole of this thickness must consist of the upper group. Between Damlai and Ratanpur the beds are folded anticlinally along an E.-W. axis; in the neighbourhood of Jhagadia they show considerable disturbance.

Foraminifera found in these upper Tertiary sandstones and conglomerates have been identified by S. R. N. Rao, one as a new species of *Lepidocyclina* and another as a variety of the Sumatran species, *Lepidocyclina* (*Nephrolepidina*) *summatrensis* Brady.[28] The commonest organic remains are valves of *Balanus* such as are abundant in the Gaj (Miocene) rocks of Sind. That the beds are younger than the Eocene is suggested by the presence of rolled fragments of Eocene limestone and calcareous sandstone in the conglomerates of the higher group; a Miocene age for the latter is not unlikely. As P. N. Bose notes, the occurrence of these agate and carnelian pebbles, the material of which undoubtedly comes from veins and geodes in the Deccan Trap, throws some light on the age of the trap and its quartzose contents. Since these particular pebbles are very rare in the Eocene conglomerates but abound in those of the younger group, it would appear that by the beginning of the Eocene stage here represented (Kirthar or Middle Eocene), sufficient time had not elapsed for the formation and erosion of those veins and geodes, the disintegration of which provided material for the agate and carnelian conglomerates of the Ratanpur-Damlai area.

The agate and carnelian pebbles of this region are usually two or three inches along their longest diameter but occasionally are very much larger. As raised from the Mines of Ratanpur and Damlai they are light-coloured, generally with a milky tinge; to improve the colour most of the stones used to be baked. An enormous amount of valuable rock has been left unworked as a result of wasteful methods of exploitation. The first authentic reference to the carnelian mines of Ratanpur dates from the beginning of the sixteenth century (A.D. 1503-1508). About this time a carnelian industry was established at Limodra by an Abyssinian merchant named Bawaghor to whom after his death a shrine was raised on a hill close to the Mines and now well known as Bawaghor Hill. In the beginning of the seventeenth century the lapidarian section of the industry seems to have been transferred from Limodra to Cambay, whither the stones were henceforth taken to be cut, polished and worked up. In 1805 the value of manufactured articles of carnelian and agate—cups, knife-handles, sword and dagger handles, rings, stones for signets, bowls, spoons, buttons, snuffbox stones, and even small cabinets 14 or 15 inches long and 8 or 9 broad—was estimated at £9,490. The mines are no longer worked.

To Cambay also comes most of the agate and related forms of silica obtained directly from the geodes and veins in the amygdaloidal flows of the Deccan Trap itself, from various States and districts on or near the edge of the Trap, the chief sources of supply being the

[28] "Current Science" 8, 167 (1939).

Kistna, Godavari, Bhima, Narbada and other rivers draining Trap-covered areas.[29] Much of the agate retailed in Europe is sent from Cambay, from which city also large quantities are exported to China.

RATNAGIRI.

Nearly 300 miles south of the Tapti, a deposit of obscure date and origin has been noted beneath laterite at Ratnagiri on the west coast.[30] White and blue clays with thin carbonaceous seams are found in various quarry and well sections near the town beneath a considerable thickness of laterite which in one case amounts to 35 feet. The beds are only a few feet thick—27 feet in one section—and rest unconformably upon Deccan Trap. Some of the clay is said to be sandy or gravelly. The deposit is capped by a layer of hard ironstone, about an inch thick but sometimes thicker. Fossilised fruits and leaves are to be seen in the clay and lignite, together with mineral resin and pyrite; no specimens of the organisms observed appear to have been described or even collected.

TRAVANCORE.

The earliest information published on the occurrence of Tertiary beds in Travancore is comprised in some notes by General Cullen to Carter.[31] The very small outcrop described was not found during the subsequent geological examination of the neighbouring State of Cochin, and the locality may have been incorrectly defined in the first instance. In 1883 specimens were sent to the Geological Survey Offices by Logan, the then Resident of Travancore, who had collected them from a limestone at a spot known as Purappakkara, about 7 miles northeast of Quilon, a somewhat greater distance than that published in Carter's notes; [32] these specimens cannot now be traced.

According to General Cullen, grey fossiliferous, argillaceous limestone (referred to by him as "dolomite"), partly compact and partly loose and rubbly, is to be found beneath the laterite of the Quilon neighbourhood, at a depth of about 40 feet from the surface. This limestone is described as exposed beneath a laterite cliff near the coast, four or five miles northeast of Quilon, and as having been found in the vicinity of the town at a depth of about 40 feet in numerous wells, many of which were sunk or deepened by General Cullen for the purpose of ascertaining the extent of the limestone.[33] General Cullen's limestone, which must not be confounded with the Warkalli beds occurring twelve or fourteen miles south of Quilon, is described

[29] Mineral Productions, Rec. 70, 390 (1935).

[30] C. J. Wilkinson, Rec. 4, 44 (1871).

[31] "(Summary of the Geology of India", Journ. Bo. Br. Roy. As. Soc. V, 301, (1857); and Geological papers on Western India, 1857, pp. 740 and 743, footnote in 1857).

[32] Ann. Rep. Rec. 17, 9 (1884).

[33] Rec. 15, 91-92, 93-95 (1882).

as containing marine shells in abundance, amongst which the following are recorded:[34]

GASTROPODA.

Strombus fortisi Brongn. (assimilated by d'Archiac with *S. sedanensis* Mart. found in the Gaj of Sind),[35]
Cassidea (Bezoardica) sculpta Sow.,
Lyria ("Voluta") jugosa (Sow.),
Ranella (Biplex) bufo Sow.,
Conus (Lithoconus) brevis Sow. ("*Conus catenulatus* Sow." of Dr. Carter, but assimilated by Vredenburg with *C. brevis*),[36]
Conus (Leptoconus) marginatus Sow.,
Cerithium (Ptychocerithium) rude Sow.

FORAMINIFERA.

Orbiculina malabarica Carter.[37]

The *Orbiculina* was a new form when described by Carter, but has since been found in another coastal locality farther north and in Ceylon; it is said to occur also in the Eocene of Kathiawar. All the mollusca identified in these beds, which are sometimes referred to as the "Orbiculina beds of Quilon", are Gaj species, and the beds cannot be very different from Upper Aquitanian or Lower Burdigalian.

The same limestone has since been recognised by C. P. Kumar and C. S. Pichamuthu in a well between Chattanur and Paravur at a depth of 46½ feet, *i.e.*, some 9 feet below the base of the capping of laterite and lateritic gravel; a similar section is recorded by these two observers at Nedungolam.[38] The limestone is described as full of fossils, among which the following have been identified:

FORAMINIFERA.

Orbiculina malabarica Carter,
Operculina cf. *complanata* d'Orb.

ACTINOZOA.

Stylophora pulcherrima d'Arch.,
Leptocyathus cf. *epithecata* Dunc.[39]

GASTROPODA.

Conus hanza Noetl.,
Rimella subrimosa d'Orb.,

LAMELLIBRANCHIATA.

Arca theobaldi Noetl.,
Nucula cancellata Vred.,

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[34] Recently M. R. Sahni and M. V. A. Sastry have described two more forms (corals) from the Quilon limestone, *Antillia miocenica* Sahni and Sastry, *Calamophyllia quilonica* Sahni and Sastry, "Current Science".

[35] E. Vredenburg, Mem. 50, 313-315 (1925).

[36] Mem. 50, 91 (1925).

[37] (See Gen. Rep. Rec. 38, 20 (1909); Journ. Bo. As. Soc., 5, 142-144 (1853); Ann. Mag. Nat. Hist., Ser. 2, 11, 425-27 (1853), Journ. Bo. As. Soc. 6, 88 (1861); Ann Mag. Nat. Hist., Ser. 3, 8, 309-333, 366-382, 446-470 (1861).

[38] Quart. Journ. Geol. Min. Met. Soc. Ind., Vol. 5, 86-89 (1933).

[39] Pal. Ind. Ser. 7 and 14, Vol. 1, pt. 2, 60 (1880).

Glycimeris (Pectunculus) sindiensis (Vred.),
Parallelipipedum prototortuisum Noetl.

These fossils indicate a Gaj horizon and are a mixture of Sind and Burmese types. Between these Tertiary beds and the laterite capping are some 9 feet of carbonaceous clay, limestone and ferruginous sandstone, perhaps the representatives of the Warkalay (?Pleistocene) formation.

The Quilon beds of Travancore have been recognised by Wayland & Davies on the Jaffna peninsula of north Ceylon, where a similar assemblage of fossils, including *orbiculina malabarica* (Carter), has been described.[10] Miocene beds of an age not far removed from that of the Jaffna and Quilon occurrences also occur in the south of the island at Minihagaikanda.

FRESH-WATER FACIES OF THE GAJ.

Sind.—On the western side of the Bhagothoro hills in Sind, four or five miles south of Sehwan, some unfossiliferous, variegated shales, clays, sandstones and conglomerates, many of them richly tinted with brown and red, rest unconformably upon the denuded edges of Lower Nari brown limestones and shales and though originally referred to the Upper Nari by Blanford, are probably of Upper Gaj age, since they are overlain by a shell bed with Upper Gaj marine fossils. Pilgrim finds these highly coloured beds very like the Bugti Bone beds, which are described below and are now assigned to the Upper Gaj. Although not continuous in outcrop with the Bugti beds they have been traced northwards beyond Dera Ghazi Khan, and in all probability represent a fresh-water facies of the basal portion of the Upper Gaj which corresponds to a large part of what is known in the Punjab and the Himalaya as the Murree series, a formation covering a very extensive area. The Murree series, however, probably embraces beds which are more recent than the uppermost limits of the Gaj and may reach upwards into the Upper Burdigalian.

The Bugti Hills.—The Upper Gaj strata of the Bugti hills, or Lower Murree beds as we may now begin to call them,[41] have been described in detail by Pilgrim and attain a maximum thickness of 1,000 feet; the beds show great lateral variation, and the same fossil species occur at different horizons.[12] For the most part the stage consists of sandstones, often of bright and varied colour, passing here and there into red and yellow sandy clays. Coarser than the corresponding beds of the superjacent Siwaliks, these beds often assume the form of conglomeratic grits with numerous quartz pebbles of the size of a pea. Beds of ferruginous concretions, sometimes conglomeratic, sometimes lateritic, are common. Ferruginous conglomerates are particularly well developed in the Puli stream-course, north of Dera Bugti, near the base of the stage, where, including some

[40] Q. J. G. S., Vol. 79, 591-592 (1923).
[41] At first mistaken for lower Siwaliks, and afterwards for the upper Nari.
[42] Rec. 37, 141 (1908).

intercalated sandstones, they occur throughout a thickness of 200 feet. Among the Upper Gaj beds of this region are soft, almost pure white sandstones, containing lenticular bands and patches of ferruginous matter; such beds weather to well rounded hillocks. One very characteristic bed, found rather high up in the local sequence, is a sandstone in which concretionary hardening has taken place irregularly, with the formation of hard branches and knobs, the intervening softer material weathering away and leaving a surface honeycombed by ramifying passages or pits; this bed typically forms the tops of scarps. A very common type of concretion is made up of numerous well-rounded or sub-angular quartz fragments, up to the size of a pea, cemented and completely coated with dark red oxide of iron; these fragments are aggregated into spherical masses of all sizes up to that of a man's head. The pebbles of the conglomerates are never composed of limestone, but either of sandstone or of quartzite; frequently they are recognisable as derived from sandstones of the Cretaceous.

With the exception of its topmost 100 feet, the Upper Gaj of the Bugti hills has yielded a large number of vertebrate bones and for that reason is often spoken of as the Bugti Bone bed. That the succession was not uninterruptedly a fresh-water deposit is proved by the gradual passage downwards of the bulk of the beds into a basal estuarine zone of conglomerate beds characterised by a mixed fauna of oysters and mammalian remains; the fossils, which occur at about 100 feet above the base of the beds, include *Ostraea gajensis* Vred., *O. vestita* Fuchs, and *O. bicolor* Hanley, all well known Upper Gaj species.[43] Below the base of the Upper Gaj is the Upper Nari with *Nummulites intermedius*. Three hundred feet up from the base are yellow sandstones with silicified tree trunks of dicotyledonous wood in abundance. At an horizon varying from 500 to 700 feet above the base occurs a zone of fresh-water shell beds, the chief fossils, *Viviparus (Paludina) bugticus* (Blanf.) and V. (P.) *atavius* Annand., sometimes making up bands six inches thick; *Melania* and *Unio* occur in more scattered fashion.[44] *V. atavius* has given rise with very little modification to a species now living in the inland delta of the Helmand, *V. helmandicus*. The occurrences in the Bugti Gaj evidently mark the sites of ponds or swamps.

Vertebrate bones and teeth are found scattered throughout the Bugti Bone beds at various horizons from the base up to within a hundred feet of the top. Some of them appear to have been gnawed and broken, probably by contemporaneous animals. The following list includes all the vertebrate species known up to the present from the Gaj series of India or its equivalent, as well as some mollusca.[45]

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[43] G. E. Pilgrim, Pal. Ind. New Ser. Vol. 4, No. 2, 1-83 (1912).

[44] N. Annandale, Rec. 51, 363 (1920).

[45] G. E. Pilgrim, Pal. Ind., New Ser. Vol. 4, Mem. 2, 3 (1912); Pal. Ind. Vol. 18 (1932); C. Forster Cooper, Pal. Ind. Vol. 8, Mem. 2 (1924); Ann. Mag. Nat. Hist. Ser. 8, 12, 376-381 (1913) and 16, 404-410 (1915); Phil. Trans. Roy. Soc. Ser. B. 223 569-616 (1934).

GASTROPODA.

Melania pseudepiscopalis Blanf.,
Melania gradata Blanf.,
Viviparus (Paludina) bugticus Blanf.,
Viviparus (Paludina) atavius Annand.

LAMELLIBRANCHIATA.

Unio vicaryi Blanf..
Unio carduiformis Blanf, and var.,
Unio cardita Blanf.,
Unio pugiunculus Blanf.

PISCES.

Siluroid genus.

CHELONIA.

Trionyx sp.

CROCODILIA.

Crocodilus bugtiensis Pilg.,
Garialis curvirostris Lyd., var. *gajensis* Pilg.,
Garialis breviceps Pilg.,
A small Cetacean ; part of a tympanic bone, having the size and general appearance of *Platanista gangetica*."

PROBOSCIDEA.

Moeritherium ? sp.,
Dinotherium indicum Falc., var. *gajense* Pilg.,
Hemimastodon crepusculi Pilg. (a genus intermediate between *Palaeomastodon* and the trilophodonts of Sansan and Simorre),
Choerolophodon palaeindicus (Lyd.),

PERISSODACTYLA.

Cadurcotherium indicum Pilg.,
Diceratherium naricum Pilg,
Diceratherium shahbazi Pilg,
Chilotherium intermedium (Lyd.),
Chilotherium blanfordi (Lyd.),
Aceratherium abeli F. Cooper,
Aceratherium cf. *albigense* (Roman),
Teleoceras fatehjangensis Pilg,
? *Ceratorhinus tagicus* (Roman),
Baluchitherium osborni (F. Cooper),
Chilotherium smith-woodwardi (F. Cooper),
Paraceratherium bugtiense (Pilg.) ; (*Paraceratherium* may be a small form or the female of *Baluchitherium*),
Paraceratherium (?) *churlandensis* F. Cooper,
Macrotherium salinum F. Cooper (a chalicothere).[47]

ANCYLOPODA.

Schizotherium ? *pilgrimi* F. Cooper.
Phyllotillon naricus Pilg.,

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[46] C. Forster Cooper, Ann. Mag. Nat. Hist. Ser 12, 263 (1923).
[47] Ann. Mag. Nat. Hist. Ser. 9, 10, 542-544 (1922).

ARTIODACTYLA.

Listriodon affinis Pilg.,
Palaeochœrus (?) *pascoei* Pilg.,
Xenochœrus (?) (? *Hyotherium*) *jeffreysi* (F. Cooper),[48]
Bugtitherium grandincisivum Pilg.,
Anthracotherium bugtiense Pilg.,
Anthracotherium (*Microselenodon*) *minus* Pilg. (?=*A. silistrense* (Pentland),
Anthracotherium ingens F. Cooper,
Anthracotherium punjabiense F. Cooper (equated by Lydekker with *A. silistrense* (Pentl.),
Anthracotherium exiguum F. Cooper,
Anthracotherium sminthos (F. Cooper),
Anthracotherium adiposum (F. Cooper),
Brachyodus giganteus Lyd.,
Brachyodus hyopotamoides Lyd.,
Brachyodus cf. *africanus* Andr. (species found in the Burdigalian of Egypt),[49]
Brachyodus pilgrimi F. Cooper,
Brachyodus gandoiensis F. Cooper,
Brachyodus strategus F. Cooper,[50]
Brachyodus strategus F. Cooper.[50]
Brachyodus orientalis F. Cooper,
Brachyodus indicus F. Cooper,
Brachyodus borbonicoides F. Cooper,
Parabrachyodus obtusus,[51]
Gelasmodon gracilis,[52]
Hyoboops naricus Pilg.,
Hyoboops palaeindicus (Lyd.),
Hyoboops (*Merycops*) *longidentatus* (Pilg.),
Hyoboops minor F. Cooper,
Ancodus ramsayi Pilg.,
Gonotelma major F. Cooper,
Telmatodon orientalis F. Cooper,
Hemimeryx lydekkeri (F. Cooper),
Gonotelma shahbazi Pilg.,
Telmatodon bugtiensis Pilg.,
Hemimeryx speciosus Pilg.,
Prodremotherium (?) *beatrix* Pilg.,
Gelocus indicus F. Cooper,[53]
Gelocus (?) *gejensis* Pilg.,
Progiraffa exigua Pilg. (an ancestor of the giraffe).

CARNIVORA.

Hayaenaelurus bugtiensis (Pilg.) (a primitive, aberrant member of the Felidae of gigantic size comparable to European species in the Lower Miocene),
Amphicyon shahbazi (Pilg.) (allied to species found in Europe in beds not earlier than Burdigalian),
Amphicyon cooperi Pilg.,
Metarctos (?, or allied genus) *bugtiensis* (C. Cooper) (Forster Cooper's *Cephalogale*).[54]

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[48] G. E. Pilgrim, Pal. Ind., New Ser. Vol. 8, No. 4, 55 (1926); C. Forster Cooper, Ann. Mag. Nat. Hist., Ser. 8, 16, 12, 519 (1913).

[49] C. Forster Cooper, Pal. Ind., New Ser. Vol. 8, No. 2, 25 (1924).

[50] Ann. Mag. Nat. Hist., Ser. 8, 12, 519 (1913).

[51] C. F. Cooper, Ann. Mag. Nat. Hist. Ser. 8, 16, 404 (1915).

[52] C. F. Cooper, Ann. Mag. Nat. Hist. Ser. 8, 12, 515 (1913).

[53] Ann. Mag. Nat. Hist., Ser. 8, 16, 406 (1915).

[54] Ann. Mag. Nat. Hist., Ser. 9, 12, 259 (1923).

[70] Bull. Geol. Soc. America, Vol. 38, 678 (1927).

In Pilgrim's opinion it is impracticable to regard any of the vertebrate species as confined to one particular horizon in the series. The fauna as a whole is widely different from that of the Lower Siwaliks of Sind and the Punjab. The specific identities are *Dinotherium indicum, Aceratherium gajense* and *Garialis curvirostris*, but all three probably possess varietal differences in the two formations. The fauna of the Bugti Bone beds indicates a Lower Burdigalian age. The most striking feature of the assemblage is the large representation of the Anthracotheriidae. Nowhere else is such variety in genera and species met with, and the original home of the family seems to have been eihter in India or in some neighbouring region. Another feature of the fauna is the gigantic size attained by many of the animals, especially in the case of genera which became extinct at an earlier stage elsewhere; examples of this are: *Hyaenelurus bugtiensis, amphicyon shahbazi, Moeritherium* sp., *Paraceratherium bugtiense, Bugtitherium grandincisivum, Crocodilus bugtiensis, Cadurcotherium indicum, Anthracotherium ingens*, and *Baluchitherium osborni*. The last is represented by some of the cervical vertebrae, parts of the skull, the femur, the tibia, part of an ulna, the humerus and several foot bones, and was of an unusual size and shape. *Baluchitherium* was an enormous rhinoceros with a heavy body on pillar-like limbs. each of which rested on three very elongated toes. With a head over a yard long and at least double the width of the largest known modern rhinoceros, and with a neck estimated to have been four feet in length, this animal had some of the appearances of both the horse and the elephant.[55] Another species, *B. grangeri* Osb., from Mongolia and the Ordos plateau in Mongolia was thirteen feet high at the shoulders and by stretching its neck could raise its head to a height of sixteen feet from the ground, surpassing in this way both the Indian and African elephant of to-day. Another animal of this type and size was *Indricotherium asiaticum* Bor. from northern Turkistan but not recorded from India. As Grabau remarks,[56] the wide distribution in Asia of an animal of this bulk indicates an absence of barriers between the different regions in which its remains are now found. The folding movement and the resultant mountain formation in the Himalaya, northwest India, Afghanistan and Baluchistan could not, therefore, have proceeded very far before the middle of the Burdigalian epoch.

In the Bugti hills the Upper Gaj is everywhere overlain unconformably by the Lower Siwaliks, except where it attains its local maximum thickness between Gandahari hill and the Sham plateau, where it is the highest formation exposed. A thin exposure intervenes between the Kirthar tract and the Siwaliks, northwest of Dera Bugti. The Upper Gaj also fringes, both to the north and south, the belt of Kirthars cropping out to the south of that town; the more northerly of these two occurrences dies out a few miles west of Singsila, while the more southerly, when traced eastwards, swings

[55] Ann. Mag. Nat. Hist., Ser. 8, 12, 376 (1913).

[56] Bull. Geol. Soc. China, Vol. 6, 190 (1927).

up in an arc towards the north between the Ghazij Shales and the Siwaliks past Fort Munro; from Drug to the Fort the beds, about 1,000 feet thick, consist of ferruginous sandstones and pebble beds.[57] In the Bugti hills there is a considerable unconformity between the Upper Gaj and the Lower Siwaliks.

NORTHWEST INDIA AND THE HIMALAYA

The Sulaiman area.—In the Fort Munro area, opposite Dera Ghazi Khan, the Bugti beds are represented by red sandstones and bright coloured clays at the base of the Lower Siwaliks.[58] In the Siri gorge, six or seven miles north of the road between Dera Ghazi Khan and Fort Munro, they include a shell band described by Blanford as resembling that found in the Bugti hills; the commonest among the badly preserved shells is a bivalve very like the *Unio cardiiformis* of the Bugti hills, another might be the *Unio vicaryi* of the same beds, while a univalve member of the assemblage is thought to be a species of *Viviparus* (*Paludina*). Some indeterminable fragments of bone were found at this horizon and also in the bed beneath, which is highly ferruginous basal conglomerate of rolled clay balls saturated with iron peroxide segregated in the form of irregular and often hollow nodules.[59] The Nari beds seen in the Pir Karoh range of the Bugti hills have here disappeared and the fresh-water Gaj rests unconformably on the lower part of the Middle Kirthar.[60] Similar beds with two species of *Unio*, one of them probably the ribbed *Unio cardiiformis*, a *Cerithium*, a *Natica* and a *Cyrena*-like shell, are again seen in the Vadur (Vuddore) Pass in the near neighbourhood. From Fort Munro to Drug, a distance of about 40 miles, the Kirthar is known to be overlain uncomformably by about 1,000 feet of these ferruginous sandstones and pebble beds belonging to the Gaj.

Further north, to the east of the Takht-i-Sulaiman a few fragments of mammalian or reptilian bones and of teeth, probably reptilian, were found by Kishan Singh in the valleys of the Shingao and Toi, in rocks of the same kind and occupying the same stratigraphical position below the Lower Siwaliks. A green calcareous shale at a lower horizon yielded a few fragmentary specimens of a strongly ribbed bivalve, probably one of the Bugti *Unios*. In the country between the Takht-i-Sulaiman and western Kohat, neither Hayden, Smith nor Murray Stuart records the presence of the Bugti bone bed or of any other part of the Murree series, and this formation is entirely absent in Waziristan.

THE MURREE SERIES

Distribution.—In Kohat a basal bed with strongly ribbed bivalve shells probably corresponds to the bed in the Bugti hills, and the

[57] W. L. F. Nuttall, Rec. 59, 118 (1926).
[58] E. W. Vredenburg, Rec. 36, 242 (1907).
[59] Mem. 20, 224 (1883).
[60] W. L. F. Nuttall, Rec. 59, 117-118 (1926).

Murree series to which it belongs forms a continuous outcrop throughout the central part of the district, pierced by many tight, irregular anticlines of Eocene and interrupted also by more open synclines and basins of Siwalik beds. Eastwards, across the Indus, where the basal bone beds have been definitely recognised, the Murree outcrops coalesce into a broad belt along the southern margin of the Kala Chitta, carrying the town of Rawalpindi, and the Punjab hill-station of Murree after which the series has been named. Where the Jhelum makes its acute bend, the formation occupies a still broader belt stretching northwards to the vicinity of Paras in northern Hazara and traversed by the Kishenganga, a tributary joining the Jhelum at the point of its sharp bend. From the Jhelum this broad outcrop extends south-eastwards along the southwestern flank of the Pir Panjal, through Punch and Naoshehra into Jammu, where it commences to contract. Below Dalhousie it is reduced to a narrow strip, but is again exposed further to the southeast as inlying folds in the Siwaliks. The main belt again expands in width in Mandi State, curving southwards to the Sutlej river in Bilaspur. Inlying strips to the west, in Hoshiarpur, Kangra and western Bilaspur, coalesce south-eastwards to form another large patch below Subathu where the beds are known as the Dagshai and Kasauli beds; these have been traced as far as a point east of Dehra Dun, about half-way between the Jamna and the Ganges. The Murree series is also exposed as inliers or as irregular fringes to Eocene inliers in the broad Siwalik tract of the Potwar Plateau between the Kala Chitta and the Salt Range.

Kohat.—The Upper Tertiaries of Kohat were classified by Wynne into Lower, Middle and Upper subdivisions.[61] The Lower and Middle, he subsequently correlated with the Lower Siwalik or Nahan[62] but in this he erred and his original assignment of his Lower group to the Murree series is nearer the truth. The thickness of this lower group, which can be traced from the Kurram river below Thal eastwards through the Kohat Salt-fields to the Indus, is given as 3,000-3,500 feet, but how close its upper boundary is to the somewhat arbitrary upper boundary of the Murree series now accepted, is not known.

The beds are described as grey and purple sandstones, slightly harder than the sandstones of the middle group, alternating with bright red and purple clays and occasional calcareous bands and the peculiar rocks known as pseudo-conglomerates. The nature of the last named will be more fully discussed when considering the Siwalik formation, of the lower part of which they are very characteristic; suffice it to say here that they are conglomerate-like beds in which the calcareous "pebbles" are believed to be of a concretionary origin.[63] The sandstones, even when of a lighter colour in the fresh condition, weather to a darker hue. The lower part of the group

[61] Mem. 11, 128 (1875).

[62] Mem. 14, 33 (1878).

[63] In the Cherat area, near Dag, the Murrees are said to include white and grey limestone intercalations (C. L. Griesbach Rec. 25, 98 (1892).

includes beds with bones, mostly of reptiles and fossil wood. Close to the base and to the Nummulitic limestone which usually underlies the group is a thin, reddish, calcareous and sandy layer with numbers of ill-preserved, strongly ribbed bivalves which might well belong to one of the *Unio* species of the Bugti bone bed or to some related form.[64] There is little doubt that these Bugti beds of the basal Murree zone are represented in Kohat; such beds, according to Wynne, are frequently ripple-marked. Besides the broken and scattered bivalves, these beds have yielded polished and striated crocodilian jaws, pointed teeth, tortoise plates, ribs and other large bones. A bone bed is recorded by Wynne immediately overlying the Nummulitic limestone in a pass near the hill of Gurgurlot, on the road from Khushalgarh to Kohat.[65]

The Murrees of Kohat overlie Eocene strata and, although there is rarely any visible discordance in dip or strike between the two formations, the gap between them covers the whole of the Nari and the earlier half of the Gaj periods. Throughout the 7,000 square miles occupied by the Murree deposits of Kohat and the Potwar plateau, the unconformity with the Eocene is shewn by the occurrence in the basal Murrees of numerous fragments and pebbles of the *Alveolina* limestone which forms the top of the Eocene of these parts, even in places where this limestone is locally absent; these limestone fragments and pebbles are accompanied or replaced by Eocene fossils, especially nummulites, in abundance, derived from the underlying formation. The higher horizons of the Murrees in Kohat have yielded plant remains, obscure fucoid markings and in one place a fossil tree trunk 60 feet in length.

The two upper groups of Wynne's Upper Tertiaries presumably represent the Siwalik. The boundary planes separating the three groups from each other are described as being of an arbitrary nature, one group passing gradually into the next: at the same time it is possible to recognise to what part of the Upper Tertiary sequence any large exposure is most likely to belong. The Upper Tertiaries, in fact, represent a great consecutive accumulation, the total thickness of which is difficult to estimate owing to its disturbed and dislocated condition; an aggregate of between 5,500 and 8,000 feet is suggested but much of the top of the succession must have been denuded away. The lowest or Murree group is distinguishable from the two younger groups by the greater hardness generally of its sandstones, the calcite veins in certain zones thereof, and the predominance of purple or red colours.

Peshawar.—Most of the area between Dag and Cherat in southern Peshawar, A. L. Coulson finds, to be occupied by typical Murree rocks, dipping generally very steeply S.S.E.'wards towards Cherat and forming an isosyncline succeeding the Cherat anticline.[66]

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[64] Wynne describes them as six-ribbed and of marine aspect (a Cardium?) but states that they are associated with numerous large crocodilian remains (Rec. 10, 118 (1877).

[65] Rec. 10, 119 (1877).

[66] Gen. Rep. Rec. 73, 86 (1938).

Northern Punjab.—The Murree sediments in the north Punjab lie unconformably, though not visibly so, upon the Eocene, wherever their base is exposed, and pass up gradually into the Kamlial or basal stage of the Siwalik.[67] The main outcrop includes the type area of Murree, a hill-station standing on the highest parts of a sandstone ridge of these rocks, and stretches south-westwards and eastwards along the foot of the Margala and Kala Chitta hills in a belt from ten to twenty miles wide with infolded members of the Eocene; from the Eocene of the Margala hills the Murrees are separated by a major thrust-fault. Across the greater part of the strike the Murree strata are here seen dipping steeply and mostly towards the north. Remnants of anticlinal crests are rare, and in most cases the only traces of anticlinal structure are seen in the presence of long narrow inliers of Eocene rocks.[68] The belt is one of severe compression in the west, and the beds have been folded in a series of tight isoclinal folds (Pinfold's "Isoclinal zone"); westwards towards the Indus, the compression has been less severe and synclines of an open character are discernible, some of them of considerable size. In the wide Siwalik tract which succeeds the Murree belt to the south (Pinfold's "Fault zone"), inliers of the Murrees are extremely few, the most important being the small one at Khaur.

The Murrees of this region consist of impure shale and sandstone bands characterised, especially in the lower portion of the succession, by a reddish purple colour. Individual beds are usually from 50 to 100 feet thick, and between the base and top of the series the proportion of sandstone is about equal to that of argillaceous sediment.[69] Frequently the shales are veined with calcite and contain patches of calcareous nodules. The sandstones are somewhat micaceous, the cementing material being calcareous or ferruginous or both. Some of them are grey or of a pepper-and-salt colour, but those belonging to the lower horizons are more often tinged with

[67] The Kamlials were originally included by Wynne in the Murree series, but the discovery therein of vertebrates belonging to the Lower Manchhars of Sind, a formation equated in every respect with the Siwalik, led to the lowering of the Murree-Siwalik boundary. Dr. Cotter has recently advocated the return of the Kamlials to the top of the Murree series (Mem. 55, 99-100, 1933) and there is admittedly much in favour of the suggestion. In the first place it coincides with Wynne's classification and makes his observations readable without any correction, and secondly, the upper boundary of the Kamlials is more easy to define than the lower which is vague and variable. The case differs, however, from that of the Pegu-Irrawadian boundary in Burma (see p. 1688) in that the Kamlials always contain fossils, by means of which they can be identified. It seems worth while, therefore, to adopt a boundary which, though ill-defined, can always be approximately drawn and is believed to coincide stratigraphically with the one in Sind and with that at the base of the Siwaliks in the Himalaya. The question is not of grave importance provided it is made clear which convention is adopted, since the sequence from the base of the Murree to the top of the Siwalik is probably uninterrupted except for local unconformities.

[68] E. S. Pinfold, Rec. 49, 140 (1918).

[69] According to Van Anderson sandstone forms the bulk of the formation.

ferruginous matter, and some of them are earthy and concretionary. For the impure, admixed type of sediment, so characteristic of the Murrees and parts of the Siwalik series, ranging from a shaly sandstone to a sandy shale or mudstone, the general term "siltstone" has been employed by van Anderson in his detailed description of these beds [70] and might be adopted with advantage. It differs from shale in having a massive character greatly predominant over the occasional lamination, and from clay in its partial induration and in the presence of minute gritty grains which make up a major proportion of its volume; the finer phases of the rock approach true clay, while the coarser ones grade into the sandstones. The cementing material is composed of carbonate of lime and iron salts. It is the argillaceous types of both Murree and Siwalik rocks which are especially characterised by a high ferruginous content and the resultant red coloration; the greater the predominance of argillaceous material in any particular stage or section of the sequence, the more deeply red is its general colour likely to be. Anderson notes that the sandstone beds often show the deeper coloration of the siltstones along their contact with the latter. Plant impressions are not infrequent, and annelid tracks are recorded.

Conglomerates with hard pebbles are not common, except at the base of the formation where, however, they are always thin and poorly developed. Ferruginous "pseudo-conglomerates" are much more frequent and sometimes contain vertebrate teeth and fragments of bone and fossil wood, especially in the basal stage of the series.

In the Murree hills the beds show a steady northwesterly dip, with a long gentle dip-slope ending against the faulted boundary along which the Eocene rocks of Hazara have been thrust over them. This thrust-fault marks the limit of the occurrence of the Murree outcrop; for several miles it is occupied by the Kaneir, a tributary of the Jhelum. Facing south-eastwards is a succession of picturesque scarps separated by secondary dip slopes. The gentle northwest slopes of the Murree ridge are liable to landslips.

The want of visible discordance between the Eocene and the Murree is surprising, especially in view of the loose nature of the topmost local Eocene bed (the Nummulite Shale) which, though easily removed, is unexpectedly persistent for long distances. No discordance in dip can be seen, and the two formations were originally thought to pass one into the other. Wynne had noticed the rolled condition of the nummulites in the basal Murrees, but it was Dr. Pilgrim who first drew attention to its important significance. His deduction of a break in the sequence was subsequently confirmed when the age of the Fatehjang vertebrate fauna was found to be Gaj and not Nari as was at first supposed. By following the strike of the beds, the unconformity corresponding to the Nari epoch can in several places be stratigraphically demons-

[70] Bull. Geol. Soc. America. Vol. 38, 678 (1927).

trated. On the northern flank of the Khain-i-Murat anticline, for example, where there is no trace of faulting between the Eocene and Murree, the latter at the eastern end of the ridge lies directly on the marine Hill Limestone, while to the west the variegated shales of the Chharat stage intervene in increasing thickness.[71] Along the foot of the Kala Chitta also, the basal Murree bed appears in some places to be in unfaulted contact with the Hill limestones instead of with the Chharat beds.[72] South of Dandi Jaswal, on the left bank of the Indus, a small dome shows the Murree rocks lying upon a massive *Alveolina* limestone which is not found in the normal Chharat sequence but which is tentatively correlated with the Kohat Shale stage underlying the Nummulite Shale.[73]

The total thickness of the Murree series in the north Punjab is extremely difficult to ascertain, owing to the isoclinal folding and frequent inversion to which the series has been subjected. Wynne has estimated it to be from 5,000 to 8,000 feet, but this included about 1,000 feet or more of Kamlial beds, which have since been transferred to the base of the Siwalik. The most continuous section is perhaps that north of the Khair-i-Murat ridge, but the northerly dipping beds here are not without local complications. An average figure, so far as the main belt is concerned, is probably in the neighbourhood of 6,500 feet, but the series thins out to the south, where it is overlapped by the Siwalik, and is not with certainty known to occur along the northern slope of the Salt Range ; here the Kamlials are thought to rest directly upon the Eocene with an erosional unconformity and basal rubble, except perhaps at the eastern end of the range where a portion of the red beds at the base of the younger Tertiaries may represent a thin intervening band of the Murrees.[74] Such a southward thinning accords with the supposition that the formation of the Salt Range had begun before the Murree epoch soon after the deposition of the earliest Upper Eocene (Lower Chharat) beds which, in the Salt Range area, are the youngest beds at the top of the succession below the Siwaliks. Anderson estimates the thickness of the combined Kamlial-Murree sequence at 1,400 feet near the Indus, 1,000 feet at the Sakesar bend in the range, increasing eastwards to 1,550 feet near Kalar Kahar and to 2,070 feet on the Diljaba ridge ; 12 to 17 miles further northeast the Kamlial-Murree section in the Bakrala anticlinal ridge is about 2,000 feet thick, and this thickness was also pierced in the Jhatla boring, ten miles north of the central portion of the Salt Range. On Mt. Tilla, twelve miles south of the Diljaba and Bakrala outcrops the thickness is 1,800 feet, but on the Chambal ridge, few miles south of this, only 900-1,000 feet of this combined sequence are present. Of the Kamlial-Murree sequence along the Salt Range, Anderson allots 900 feet and upwards to the Kamlial.[75]

[71] E. S. Pinfold, Rec. 49, 147 (1918).
[72] E. H. Pascoe, Mem. 40, 388 (1920).
[73] Gen. Rep. Rec. 63, 138-9 (1930).
[74] See G. de P. Cotter, Mem. 55, 106-108 (1933).
[75] Bull. Geol. Soc. Amer., Vol. 38, 685-686 (1927).

Between the base and the top of the Murree series, local unconformities have been noted. The series can be divided into a Lower and an Upper stage, distinguishable from each other by their general appearance but passing insensibly the one into the other across a boundary which is somewhat vague and arbitrary. The most easily recognisable portion of the sequence is a fossiliferous zone at the base of the Lower stage known as the Basal or Fatehjang zone, corresponding to the Bugti Bone beds, though of much smaller thickness.

The Fatehjang zone consists of brown ochreous sandstones, sometimes hard and micaceous, alternating with subordinate purple and sometimes earthy shale or siltstone, and much pseudo-conglomerate. The latter is characterised by vertebrate remains and by rolled Kirthar nummulites and assilines. The basal bed is either a conglomerate, a foot or more in thickness, with pebbles of limestone, or a ferruginous sandstone or pseudo-conglomerate, often crammed with these remanié foraminifera, derived from the Nummulite Shale which forms the youngest member of the Eocene succession below; its dark and weathered surface often presents beautifully clear sections of white nummulites which, from a distance, demonstrate the aptness of their name by their close resemblance to rupees and two-anna pieces. Beds with derived nummulites of this kind are not confined to the basal Murrees but are seen occasionally in the basal Siwaliks and range as high as the Middle Siwaliks. The same statement applies with reference to vertebrate remains which are found in all stages to the top of the Siwalik, but are compartively rare in all but the basal zone of the Murree. The thick-shelled oyster, *Gryphaea* (*Pycnodonta*) *brongniarti* Bronn, also frequently occurs more or less waterworn, in this basal conglomeratic zone of the Murrees. Locally a conglomerate of shale flakes of the "pseudo-conglomerate" type assumes the role of a basal conglomerate, lying directly on the Eocene. The thickness of the zone at Fatehjang is about 200 feet, but the upper limit is not easy to define; in some places along the foot of the Kala Chitta there are two basal bone beds with rolled nummulites, separated by eight feet of sandstone. All the vertebrate forms found are identical with Bugti species; from the type area of Fatehjang come:

ARTIODACTYLA.

Anthracotherium bugtiense Pilg.,
Brachyodus giganteus Lyd.,
Brachyodus cf. *africanus* Andr.,
Palaeochœrus pascoei Pilg.

PERISSODACTYLA.

Hemimeryx sp.,
Teleoceras fatehjangensis Pilg.,
Aceratherium blanfordi (Lyd.).

CARNIVORA.

Amphicyon shahbazi Pilg.

Besides the type locality of Fatehjang, this zone has been recognised in the Khair-i-Murat area, where it has yielded vertebrate remains in moderate abundance. In the Chorgali section it has a well-marked basal conglomerate with derived nummulites and large subangular boulders of limestone; westwards this conglomerate is replaced by a hard, massive, nodular limestone, some ten feet thick, which may be a re-cemented limestone conglomerate.[76] The Fateh-Jang zone has been encountered in the boring operations of the Attock Oil Company in the Khaur oil field.

The Lower Murree stage has a thickness of the order of 4,000 feet, but an accurate estimate is impossible. Excluding the Basal Zone, the purple and dark green sandstones of this stage are hard and micaceous, and finer in grain than those of the Kamlial or Nagri stages in the Siwalik. The clays, siltstones and shales, red and purple in colour, are subordinate in amount to the sandstones. Occasional pieces of fossil wood are found, but vertebrate fossils are rare; most of the latter are reptilian but a well preserved tooth of an anthracothere assigned to the genus *Hyoboops* is recorded from near Kali Dilli. Pseudo-conglomerates are common, but true conglomerates with hard pebbles are rare. The Lower Murree gives rise to a striking terrain as a result of differential weathering in steeply dipping alternating beds of different hardness. The result is a system of long wall-like ridges of sandstone separated by equally long narrow valleys of shale or clay. Four or five miles from the Indus, north and north-east of Nara, a remarkable topographical feature in the form of a natural theatre has been produced by an elliptically disposed range of strike hills occupied by an elongated synclinal basin of Lower Murree rocks.[77]

The Upper stage, over 1,000 feet thick, shows a distinct change in the type of sediment and, when present in bulk, is easily distinguished from the Lower. The passage from one to the other is so extremely gradual, however, that it is impossible to draw any but an arbitrary boundary which may vary in position from place to place. While the Lower Murrees are predominantly arenaceous, the Upper contain rather more clays than sandstones. The majority of the latter are greenish or grey, or of a pepper-and-salt colour, and coarser, much softer and more easily weathered than the sandstones of the stage below. The tints of the clays are more of a cherry red and less of a purple colour, while some of them are grey. Bands of pseudo-conglomerate are still common.

In the Attock district a rhinocerotid tooth described as *Aceratherium* cf. *gajense*, *Mastodon* remains, and other fragmentary vertebrate fossils, have been collected from these beds. Petrified wood is not infrequently found, as well as impressions of leaves, among which are those of *Sabal major* Heer,[78] a palm found also in the

[76] E. S. Pinfold, Rec. 49, 150 (1918).
[77] Gen. Rep. Rec. 63, 139 (1930).
[78] G. E. Pilgrim, Rec. 40, 188 (1910); O. Flestmantel, Rec. 15, 51-53 (1882).

Kasauli beds of the Simla area.[79] The dicotyledonous wood is said to be indistinguishable from that found in the basal Siwaliks.[80]

The Upper Murrees, which resemble very closely the Chinji beds of the Siwalik series, are exposed to the northeast of Rawalpindi, and occupy a narrow zone of complex structure on the south side of the Khair-i-Murat ridge. They also cover a small elliptical area in the Khaur dome, where they are the youngest strata exposed; more than 1,500 feet of beds assigned to the Upper Murree stage have been bored through in this oil-field. Upper Murrees occupy a large area between Khunda and the Mianwala strike fault; along the latter they are brought into juxtaposition with the Chinji stage of the Siwaliks.[81] There is a small asymmetric dome of Upper Murree beds between Mari and the river Indus, and other exposures of the same beds in other parts of northwest Attock.

As in the greater part, if not all, of the Salt Range, so also in its trans-Indus continuation, it is doubtful whether the Murree series is present.

Kashmir.—The Murrees project northwards in the form of a V-shaped outcrop in the syntactical angle made by the Himalaya with the Hazara mountain system, the boundary with the Eocene or older rocks on both sides being a thrust fault. Here the folding has been so intense that it is difficult in some places to distinguish between Murree strata and the numerous thin bands of Chharat limestone which wind their way through the former, producing a false impression of transitional passage.[82]

More than a third of Punch State is occupied by a broad belt of Murree rocks, 24 miles across in the north and 18 in the south. The inner limit of the Murrees is underthrust against the older rocks along the foot of the Pir Panjal, while the outer border indicates various relationships with the belt of Siwaliks. Northwards the Siwalik series is said to overlie the Murree in a normal fashion but at Kotli and to the southeast thereof the junction with the Middle Siwalik is a reversed fault which is a continuation of the so-called "Main Boundary Fault" of the Jammu hills. Except along the periphery of the Siwalik basin the Murree strata of Punch are inverted; contortion is common and local faults are responsible for much slickensided debris. East of Kotli an inlier of the "Great Limestone" projects through the Murrees; two other inliers of the same rocks, accompanied in one case by the Eocene of the Sangar Marg coalfield, are seen northeast of Riasi.

The Murree beds of Punch are folded in the same isoclinal series of narrow compressed folds as that seen along the northern Potwar, and again there are found winding strips of Chharat limestone among the younger bed.[83] Many such limestone intercalations are seen in

[79] Gen. Rep. Rec. 61, 127 (1928).
[80] D. N. Wadia, Mem. 51, 339 (1928).
[81] Gen. Rep. 61, 127 (1928).
[82] D. N. Wadia, Rec. 65, 214 (1931).
[83] At first regarded as a marine episode in the Murree epoch (D. N. Wadia, Mem. 51, 265-266, (1928).

the section exposed along the Kishenganga valley, but some of them may belong to the Murree series among which they occur. The Murrees of the Kishenganga valley are predominantly shaly in spite of the fact that they belong probably to the Lower stage.

The Murrees of Punch are divided by Wadia into a Lower stage, not more than 4,000 feet thick and perhaps less, and an Upper between 1000 and 2,000 feet, the distinction between the two being more marked than it is in the northern Potwar. At the base of the Lower stage is the representative of the Fatehjang zone, from 20 to 200 feet thick, consisting of a pseudo-conglomerate with clay concretions and ossiferous in places. A few of the bones are mammalian (ungulate) but most of them are chelonian, among which *Trionyx* has been recognised. There are also recorded from this zone some rare leaf impressions, both monocotyledonous and dicotyledonous, and in one locality a few large thick valves of a unionid lamellibranch.

The rest of the Lower Murrees, in which plant remains are absent or very rare, consist of hard, fine-grained, non-micaceous, slab-like sandstones, deep red, purple or grey in colour; frequent bands of pseudo-conglomerate; red and purple, splintery shales with occasional bands of green phosphatic shale, seamed abundantly with calcite; and thin argillaceous limestone partings.[84]

The Upper Murrees of this area form as it were a wide zone of passage beds between the Lower Murrees and the Siwaliks, and approach closer to the latter in composition, texture and the topographical features they give rise to. They are coarser in grain than the Lower Murrees, less charged with iron and calcareous matter and therefore much brighter in colour. The Upper Murree stage comprises: soft, crumbling, coarse, micaceous sandstones of pale grey and brown tints, with hard central cores; and red, purple, grey and buff shales. No fossil bones are recorded but plant remains are numerous in both sandstones and shales. The folds in this younger stage are more open, with rolling gentle dips, in marked contrast to the isoclines of the Lower stage. The general aspect of the Upper Murree outcrops, like that of the Siwaliks, is one of rounded hill-sides of light brown colour; this feature is no doubt partly a result of the gentler dips. The Upper Murrees according to Wadia, are exposed in two elliptical basins, one, the Mendhar basin, 16 miles long, north-west of Punch, and the other the Bagh valley, 20 miles long, S.S.E. of the same city; they are also mapped as forming a border to the main Siwalik basin of Punch for some distance, intervening between the Lower Murrees and the Siwaliks, in a fitful outcrop which broadens and narrows and finally dies out as the result of overlap by the Siwaliks. Where the succession is complete, the Upper Murrees are said to pass up into the Palandri, a formation which Dr. Wadia has correlated with the basal or Kamlial stage of the Siwalik. It is possible, however, that some at least of the beds in Punch mapped as Lower Siwalik belong really to the Murree formation. The so-called Lower Siwalik of this region have been divided into two stages,

[84] D. N. Wadia, Mem. 51, 270 (1928).

the Palandri below and the Mang above. It is admitted that the rocks have a different facies from that of the Lower Siwaliks in the Jammu hills and Kangra further southeast or in the Salt Range to the West, and that they are physically more analogous to the Murrees than to either the Kamlials or Chinjis, especially in their deep purple coloration, their highly calcareous composition, the presence among the sandstones of thin beds of fresh-water limestone or marl, and their greater induration. The well marked two-fold division of these supposed Lower Siwaliks corresponds with that into Kamlial and Chinji neither in petrological character nor in thickness dimensions, the Palandri being 4,000 feet and the Mang 3,000-4,000 feet. The Palandri stage, seen more or less fringing the main Murree outcrop or forming the cores of steep Siwalik anticlines, is composed of pebbly sandstones and purple clays, in which scattered bones of freshwater reptiles and land mammals, mostly ungulates, are by no means rare. The commonest remains are faint carbonised impressions of angiospermous leaves among the clays and badly silicified wood in the sandstones. The animal remains include teeth, limb bones and dorsal scutes of *Crocodilus* and *Garialis*, a canine tooth and other remains of an aceratheroid rhinoceros, and coastal plates of *Testudo* and *Emyda*.[85] *Tetrabelodon* and *Dinotherium*, so frequent in the Kamlial of the Potwar, are represented by a single fragment of a tooth. At Palandri itself, some of the limestones and marls have yielded numerous discs and valves of fresh-water crustacea, molluscan shell valves and opercula of ampullarid gastropods, the commonest being *Pachylabra prisca* Prashad.[86] The Mang stage, which grades into the Palandri, is more shaly and contains thick intercalations of very hard and compact calcareous clay. The Mang beds, forming irregular but wide and open synclines, generally form high ground and occupy a large part of southern Punch. Petrified wood is less common but some of the fine clay beds are often full of leaf impressions. The beds are more ossiferous than the Palandris and have yielded a few determinable bones and teeth which were described as indicating on the whole affinities with Chinji fossils of the Punjab ; nonetheless of the only two vertebrate forms specifically identified, *Aceratherium bugtiense* is not found above the Upper Gaj (Bugti bone-bed), while the other, the so-called *Dinotherium indicum*, which Palmer has shown to be inseparable from *D. giganteum*, is represented varietally in the Upper Gaj and ranges up into the Dhok Pathan stage of the Middle Siwalik. A species of *Hemimeryx* has been collected from these beds but is smaller than the Chinji species, *H. pusillus*, and therefore also smaller than the Gaj species, *H. speciosus* which is larger than *H. pusillus*. Rhinocerotid remains are said to be the most common of the forms found.

In Jammu also the Murrees are divisible into a Lower stage of hard, fine-grained, calcareous sandstones, purple splintery shales and nodular clays, and an Upper of comparatively soft, fine or sugary-

[85] D. N. Wadia, Mem. 51, 274 (1928).
[86] B. Prashad, Rec. 56, 210 (1924).

textured sandstones, of pale yellow, grey or grey-brown colour, and reddish shales and clays. As usual the boundary between the two stages is vague and indefinite. The rocks of the Upper Murrees of this area show neither the high inclination nor the crumpling seen in the Lower, and form prominent dip-slopes and scarps; they pass up into the Kamlial stage of the Siwalik. The Murree sandstones of this region are ripple-marked and break into large blocks along well-developed joint-planes; some of them have yielded plant remains.[87]

Mandi state and the Simla foot-hills.—In Mandi State and the hills below Simla the Murrees are known under the names of the Dagshai and Kasauli formations, corresponding respectively to the Lower and Upper Murree.[88] Of the tract in Mandi, originally mapped for the most part as Nahan, there is little information. In the Sutlej valley the purple Dagshai clays and sandstones are described as passing up, through beds with fossil palm wood and a variety of *Mastodon angustidens* older than the Chinji form, into beds of Chinji (Nahan) age.[89] These intermediate beds must represent either the Kasauli stage or the Kamlial stage or both; in many localities they are absent and the Chinjis are seen resting with strong unconformity upon the Dagshais. A well marked band of Krol and Eocene rocks in one part of the area divides beds of Dagshai character on one side from Kasauli deposits on the other; the latter have yielded a unionid identified as *Indonaia*.[90]

Here may be mentioned the well known gas springs of Jwalamukhi, a samll town in the Kangra district, 15 miles south and a little east of Kangra itself. These natural jets of combustible gas, which have been celebrated for numbers of years and are believed by Hindus to be a manifestation of the Goddess Devi, occur on a faulted anticline composed of a core of Dagshais flanked by Siwalik sediments. On the Dagshai outcrop, which is some 8 miles in length, a temple has been built over the gas seepages. The gas probably originates from unexposed Subathu (Upper Nummulitic) beds, its escape being facilitated by the fault; no oil accompanies it. One brominiferous and five or six iodiniferous springs are known in the chain of hills bordering the Jwalamukhi valley on its northeastern side, along the right bank of the Beas. In the one case 100,000 parts of saline water contain 1.2 parts of sodium bromide; in the other cases the same number of parts of saline water contain from 10 to 12½ parts of potassium iodide.[91]

In the Simla foot-hills the Dagshais of the type area are folded synclinally and are overthrust along their northeastern boundary by older rocks of the Krol series; this is well seen around the north-west end of Pachmandra hill as well as along the Blaini river. The

[87] Gen. Rep. Rec. 73, 93 (1938).
[88] R. R. Oldham regarded the Dagshai and Kasauli beds as local variations of the same stage, but may have been confused by erroneous mapping. There is good reason to believe that there are two distinct stages of different lithology and age.
[89] Gen. Rep. Rec. 55, 41 (1923).
[90] Gen. Rep. Rec. 58, 60 (1925).
[91] E. H. Pascoe, Mem. 40, 441-442 (1920).

Krol rocks, as well apparently as the thrust-plane, have been bent synclinally, with the result that thin traces of the Dagshai beds are seen along the inner or north-eastern margin of the syncline of older rocks. The Kasaulis are exposed on the southeastern side of an irregular outcrop of Subathu beds which here separates them from the Dagshais. Interrupted patches of the Dagshai-Kasauli series are exposed along the trace of the thrust-fault to the southeast as far as the vicinity of Dadahu ;[92] a few miles further on, the same beds come in again and are seen as far as a point west of Dehra Dun. The Dagshahi-Kasaulis have themselves been thrust along another steeper reversed fault— the so-called "Main Boundary Fault"—over the Lower Siwaliks (Nahan).[93] One of the most interesting occurrences of Dagshai beds is that below a tectonic "window" in the Shali area, northeast of Simla ; here the beds are seen around Katnol consisting of carmine shales and purple and green sandstones.[94]

In all these regions there is the same break between the Subathu and the Dagshai, and the same absence of any visible discordance between the two groups along non-faulted contacts. The basal beds of the Dagshai stage consist of a peculiar pisolitic marl made up of small calcareous concretions scattered through a matrix of red clay, a white sandstone full of irregularly shaped, highly ferruginous concretions, some inches in diameter, and pure white sandstones, associated with dark purple shales differing markedly in appearance from the general type of those above or below them ; in the neighbourhood of Kasauli, Auden finds a well-defined white quartzitic sandstone intervening between the more typical Dagshais and the Subathus.[95]

The rest of the Dagshai stage consists for the most part of alternations of purple, cindery, sandy shales, and hard, fine-grained, purple or greenish grey sandstones, in beds up to 15 feet in thickness. The scenic effect between the towns of Dagshai and Subathu of this very regular alternation of sandstone and shale in more or less equal proportions is very striking. Current-bedding and ripple-marking are common in these beds. Conglomerates form part of the sequence and contain fragments of red shale derived either from the Subathu series or from contemporaneous erosion of Dagshai shales, as well as limestone fragments of the same type as those found in the Subathu conglomerates. The shales, which are homogeneous and weather typically into small rounded nodules, prevail in the lower part of the group, where the sandstones, though occasionally rising to a thickness of 50 feet, form but a small proportion of the succession in the upper portion of the stage ; the sandstones increase at the expense of the shales, till at the top there are 200 or 300 feet of sandstones with a few thin bands of red shale, which it is impossible to class definitely either with this stage or the Kasaulis. According to Auden, an examination under the microscope of the Dagshai sandstones shows them

[92] J. B. Auden, Rec. 67, Pl. 25. (1933).
[93] J. B. Auden, Rec. 71, 416 (1936).
[94] Gen. Rep. Rec. 71, 72 (1936).
[95] Rec. 67, 388 (1933).

to be seldom calcareous, and to include fragments of phyllite, carbonaceous slate (derived perhaps from the Infra-Krol or Subathu), Subathu-like sandstones, and in rare cases limestone; the minerals identified in these sandstones include tourmaline, garnet, plagioclase, kyanite, zircon and derived glauconite. The textural appearance of the Dagshai sandstones is described as one of initial loose packing of phyllite and slate fragments with sand, and their subsequent compression resulting in the out-splaying of the phyllite to produce a new matrix.[96] In places the term quartzite might be applied to the Dagshai sandstones, occurring as irregularly jointed, massive beds, from 6 to 20 feet in thickness, subordinate in amount to the shales, showing no stratification, and projecting in rugged outcrops. The only organic impressions in the Dagshais are some fucoid markings and annelid tracks.

As in the case of the Murree series of the Punjab, there is no definite boundary between the Lower and Upper stages of its equivalent in the Simla hills, the change from Dagshais to Kasaulis being perfectly transitional. Jointing is more irregular in the Dagshais than it is in the Kasaulis, but both stages are folded in a much simpler and more regular manner than the Subathus. The Kasaulis, which in general character approach close to the Nahan group or Lower Siwaliks up into which they pass conformably in the Kangra district, are essentially a sandstone formation with quite subordinate argillaceous beds, and in this way differ from their equivalents, the upper Murrees. From the Dagshais they differ in the infrequency of purple colouring and in the predominance of sandstone over shale. The sandstones are massive and mostly grey or greenish in colour, and although many of the beds are as hard as any in the Dagshai stage, they are in the aggregate softer, coarser, more micaceous, and at times felspathic; garnet is a common constituent. The shales are less cindery and greener in colour than those of the Dagshais, and in some cases are hardened to clay slate; in the Kasaulis, in fact, soft green needle shales are to be seen interbedded with clay slate. Some of the shales contain fragments of palm leaves, among which *Sabal major* Heer has been recognised. At Nalagarh a fragmentary proboscidean tooth has been found in the Kasaulis, associated with fossil wood. Auden notes that the Dagshais are the earliest Himalayan rocks in which the conglomerate pebbles include metamorphic rocks and minerals of meso-type; in both the Dagshais and the Kasaulis garnet is abundant and pebbles of recrystallised quartz schist occur."[97]

In the Siwalik hills below Dehra Dun the Dagshai-Kasauli succession is faulted against the Nahan, which has been thrust over it. This Krol thrust—or "Main Boundary Fault"—as it has been called by Middlemiss, does in fact form the northern boundary of the Siwalik exposure over much of the area between Dehra and Naini Tal[98]. East of longitude 78° E. the Dagshai-Kasauli beds are very

[96] J. B. Auden, Rec. 67, 388 (1913).
[97] Rec. 67, 417 (1933).
[98] J. B. Auden, Rec. 71, 416 (1936).

seldom seen. Between Dehra and Rikhikesh ("Riki Kase"), the Dagshais are probably represented by some cindery nodular sandstones which, accompanied by Eocene rocks, are exposed in two windows; here both formations rest upon Simla Slates and have been overthrust by the rocks of the Krol nappe[99].

Mode of accumulation of the Murree series and its equivalents.— Various opinions have been expressed concerning the mode of accumulation of the Murree and its equivalent sediments. Most observers now regard the post-Eocene succession of the Punjab, although showing variations in colour, mineral grain and the grouping of beds at different horizons, as essentially a single system of deposits of a comparatively homogeneous type; for this system R. Van Anderson has proposed the term Nimadric[100]. On the other hand, it has been suggested that the more ferruginous deposits, especially the red and purple beds of the Lower Murree or Dagshai, were deposited in lagoons, while the lighter coloured sediments are more purely fluviatile. The latter suggestion was made when the lowest Murrees were thought to be of Nari age and to have followed the Eocene with no break greater than that involved in a change from marine to lagoonal conditions. One definite fact is that the place of the marine Eocene gulf, which stretched along the foot of the Himalaya, across the Potwar area and down through Sind to the Arabian Sea, was eventually taken by a large river in Siwalik times. Between the marine and fluviatile periods there must have intervened a period of lagoon conditions bridging over the change, and the question which remains to be solved is whether this lagoon period was largely restricted to the Nari and has left no exposed relic, or whether it persisted into the Lower Murree and Dagshai. The contrast between the purple beds of the Dagshais or Lower Murrees and the lighter coloured strata of the bulk of the Kasaulis and Siwaliks has no doubt been mainly responsible for the suggestion of deposition under different conditions, and the fact that red Murree-like rocks occur in the local Eocene (Chharat stage) is proof that the change commenced before the Murree period.

An ingenious suggestion by Pilgrim provides an alternative and more acceptable explanation of the cause of the colour difference. It is that the strongly ferruginous sediments were derived from the southern side of the main river valley, *i.e.*, from highly lateritic soils covering the low mature drainage of the Peninsula and formed from the iron-bearing pre-Cambrian rocks of Rajputana, while it was the Himalaya and other hills along the northern mountainous side which later on supplied the lighter coloured silts for the Siwaliks.[101] In

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[99] Rec. 71, 416 (1936).

[100] Bull. Geol. Soc. Amer., Vol. 38, 673 (1927).

[101] Wynne's statement that the paler coloured sandstones become more frequent in the Murrees as we pass southward, in the direction of the Peninsula, might seem to be against this view, but Wynne included the Kamlials in his Murree series, and the latter, *sensu restricto* is scarcely represented at all along the southern margin of the Potwar

other words, since the red colouring is probably due to the tapping of a drainage system mature enough to support a lateritic soil, the red silts are more likely to have come from the Peninsular side where the drainage was of a mature type. On the other hand, the lighter-coloured sediments are more likely to have been derived from the Himalaya, an unquiet region of protracted movement, where conditions would have been too disturbed for the formation and accumulation of any appreciable deposits of laterite. This suggested origin of the red and purple beds might reasonably be extended to the red and purple horizons throughout the Nimadric sequence, including the ferruginous stages which form part of the Siwalik. No doubt a red coloration might have followed the tapping by tributary streams of any gently inclined surfaces capable of accumulating soil, whether north or south of the main river, but that such gentle slopes must have been largely confined to the Peninsular or southern side can hardly be disputed. On this hypothesis, the gradual rise of the Himalaya would have enabled the lighter coloured sediments to replace to an increasing extent, but with irregular interruptions, the red and purple deposits derived from the northern part of the Peninsula. In agreement with this suggestion is the identification of rock pebbles with planed surfaces and angular forms caused, in the opinion of B. R. Mackay, by glacial abrasion, found among the lenses of gravel in the Middle and Upper Siwaliks where the lighter coloured sediments predominate.[102] In the light of such a suggestion it is easy to understand the intimate association in the Murree-Siwalik succession of beds formed as a result of intense chemical action with beds derived from pronounced fluvial erosion.[103]

Whether the lagoonal phase of sedimentation is or is not represented by the Lower Murrees, the red colour of these and younger stages seems readily explicable on the supposition of a lateritic derivation. In sections where the Murrees and Siwaliks are in unfaulted contact, there is no break but clear indications of continuous deposition from one epoch to the other, and there is no real evidence against the existence of a continuous river sedimentation from the base of the Murree to the top of the Siwalik, contemporaneous with the marine deposits of the Upper Gaj and the succeeding fluviatile silts of the Manchhars in the Sind area, or with the higher portions of the Kojak Shales and the overlying marine Makran beds of southern Baluchistan.

ASSAM.

Basal unconformity.—The upper boundary of the Barail bed is marked by one of the most prominent features of the Tertiary succession in both Lower and Upper Assam, viz., a widespread unconformity which in the Surma valley can be recognised by the rapid variation in thickness of the beds immediately underneath it

[102] R. V. V. Anderson, Bul. Geol. Soc. Amer., Vol. 38, 681 (1927).

[103] P. D. Krynine, Amer. Journ. Sci. Ser. 5, Vol. 34, 445 (1937).

belonging to the Renji stage of the Barails, by the presence of conglomerates above it, and by the varying nature and thickness of the overlying beds. Some interesting work by the geological staff of the Assam Oil Company on heavy or accessory mineral residues shows that while the Barail sandstones are characterised by a very small proportion of such minerals as well as by paucity of species, above the unconformity the heavy minerals are both more abundant and more varied ;[104] the proportion of ilmenite and magnetite at the same time becomes less while staurolite, which is usually absent or rarely present in extremely small proportions in the Barail sandstones, is almost invariably found in the rocks above the unconformity. As higher horizons are examined, the variety of these minerals increases

The Surma series.—The formation above this unconformity has been named by Evans after the Surma valley, where it is best exposed, and occurs also in the Garo and Khasi Hills, the hills of north Cachar, and parts of Upper Assam. With a maximum thickness of at least 12,000 feet, it consists of alternations of shale, sandy shale, mudstone, shaly sandstone, sandstone and thin bands of conglomerate. The Surma series differs from the underlying Barails or Coal Measures and also from the overlying Tipam rocks in the paucity of carbonaceous matter ; the iron-staining and sulphurous efflorescenses, so common in the Coal Meaures are not found in the Surma rocks. In north Cachar and the Mikir hills the Surma series, with its basal conglomerate, overlaps the Barails and rests sometimes upon the Jaintia series, sometimes upon the Metamorphics. In the Lakhimpur district and the Sadiya Frontier Tract beds of Surma type overlie the Coal Measures.[105]

The Surma beds pass up conformably into those of the Tipam series. As in Burma, so in Assam, the same difficulty is experienced in tracing the various Tertiary groups from one place to another, especially from the head of the gulf or river in which they accumulated to its debouchure or *vice versa*. Here again there is a strong suspicion that the time planes intersect the lithological planes. A lithological classification is the most practical one, for the present at any rate, and has been wisely adopted by Evans in the case of the Surma and Tipam formations, the boundary plane between which is almost certainly not a time division. The upper or Boka Bil stage of the Surmas can be seen in the Surma valley passing up vertically without a break into the Tipam series ; further north, there is not only this upward vertical passage, but the upper portion of the Boka Bil stage has every appearance of passing laterally into the Tipams. The lower portion, therefore, of the beds in the north mapped and described under the heading of Tipam, corresponds in all probability to at least the higher lying portion of the Boka Bil stage.

The Surma series occupies a strip along the northeast side of the Surma valley and crops out in many neighbouring inliers. In the

[104] P. Evans, Trans. Min Geol. Inst. Ind., Vol. 27, 244 (1932).

[105] This section is compiled mainly from Evans excellent paper (Trans. Min. Geol. Inst. Ind., Vol. 27, 206 (1932).

eastern part of the north Cachar hills, it has decreased in thickness but forms a broad outcrop which includes some striking exposures seen from the railway. In the Naga Hills the beds occur in long narrow outcrops ; further northeast they reappear in the Assam coalfields overlying the Coal Measures (Tikak Parbat stage).

The Surma series shows marked lateral variation, but has been divided by Evans into the following subdivisions which are recognisable over a distance of 200 miles:

Boka Bil stage	(3,000-5,000 feet).	
		Upper.
		Middle.
Bhuban stage	(4,000-8,000 feet).	Lower.

The best exposed and fullest section is seen in the Jenam river, where all but the topmost beds are present.

The Bhuban stage, named after the scarp of the Bhuban range which forms the western border of Manipur, consists of the usual alternations of sandstone and shale, both forms of rock showing admixture one with the other, and a few conglomerates, the argillaceous beds predominating in the middle part of the stage. Both sandstones and shales are somewhat purer in the lower portion of the formation. One of the conglomerates from the country east of the Madhura and south of Haflong contains sub-angular pebbles of sandstone up to six inches across. Some of the sandstones carry fragmentary fossils.

In the Garo Hills, where coarse ferruginous sandstones predominate, there is a more or less complete sequence in the Khasimara river section. In Sylhet the Lower and Middle Bhubans are each 1,700 feet thick, and the Upper Bhubans from 1,850 to 2,000 feet. In the neighbourhood of Jaintiapur the Lower part of the stage is missing or very thin, the Middle is 2,500 feet thick and the Upper 2,000 feet. Further to the east the Middle and Upper sub-stages give sections of 1,600 and 2,100 feet respectively, while in the Larang river the Lower Bhubans reappear and attain a thickness of 2,000 feet near Kurkuri ; the total thickness at the latter locality is estimated by Evans to be 5,600 feet. In the Hailakandi valley of Cachar the Upper Bhubans have swelled to a maximum of 3,000 feet but diminish to 2,000 feet in the Bhuban hills further east. North and a little east of the latter the Jenam river section shows: Lower Bhubans, 2,800 feet, Middle, 1,700 feet and Upper, 2,700 feet, with a total of 7,200 feet. North of the Haflong-Disang fault, in north Cachar, the Lower Bhubans are absent and the Middle, sometimes with a basal conglomerate, rest unconformably upon the Barails. Evidence of the presence of the Bhuban stage is seen in the Dhansiri valley but, further to the west, from Lumding northwards to the Mikir hills, the Bhuban stage is apparently completely overlapped by the Boka Bil. In the Naga Hills, where the Surma series is disturbed by strike faults and exposed in a number of long narrow strips, the Bhubans are characterised by a large development of conglomerates marking the position of local unconformities, the Upper sub-stage is recognisable in several sections, varying in

thickness from 950 to 2,450 feet, while about 1,600 feet of the Middle Bhubans are present in the southwest of the district.

From Kanchanpur in Sylhet, four miles W.S.W. of Hailakandi, several fossils have been collected from a sandy mudstone near the top of the Bhuban stage. The whole of the material has not yet been described but the identifications so far made are all either forms found in the Pegu series of Burma or closely related thereto, and the horizon appears to correspond with some stage of the Upper Pegu, a little below the Kama, and correspond to the Acquitanian of Europe or the Lower Gaj of western India; since the fossil bed occurs high up in the Bhuban stage, the latter may extend downwards into the Chattian. The following have been determined by P. N. Mukerjee.[106]

LAMELLIBRANCHIATA.

Isocardia (Meiocardia) cf. *metavulgaris* Noetl. (typical of and restricted to the Singu stage of the Pegu series),
Isocardia (Meiocardia) sp. nov.,
? *Nucula alcocki* Noetl.,
Mactra protoreevesi Noetl.,
Leda virgo Mart.

GASTROPODA.

Drillia (Crassispira) cf. *dalabeensis* Vred.,
Drillia (Crassispira) cf. *protointerrupta* Noetl.,
Pyrula dussumieri Valenc.

CIRRIPEDIA.

Hipponyx sp., *Balanus (Chirona)* cf. *birmanicus* With.

ACTINOZOA.

Flabellum distinctum Noetl.,
Dendrophyllia sp.

ECHINOIDEA.

Cidaris sp.

Drillia (Crassispira) dalabeensis has hitherto not been found outside Burma and Assam; *Pyrula dussumieri* is very close to *P. ficus* (Linn.) from the Makran beds of Baluchistan and the Pliocene or Miocene of Java.

The Boka Bil stage, characteristically occupying long strips of marshy ground, has been so named by Evans after one such strip in the Hailakandi valley. The low ground is usually broken through by long narrow ridges or lines of low hills, but exposures are mostly poor. The thickness of the Boka Bil stage varies from about 3,000 to 5,000 feet, the maximum occurring in the hills south of Badarpur in western Cachar.

In the Surma valley, the Boka Bil stage is made up of sandy shales, ferruginous sandstones which may be massive or current-bedded, and alternations composed of laminae of shale and of ferru-

[106] Gen. Rep. Rec. 61, 20 (1928); Gen. Rep. Rec. 62, 23-25 (1929).

ginous and often coarse sand-rock. In some localities ferruginous, Tipam-like sandstones predominate, and the stage as a whole passes up into the Tipam series. In the Garo Hills the Tipam-like sandstones within the formation become unusually coarse and contain many conglomeratic beds ; in this direction a close approach to a shore-line seems indicated. The Boka Bil stage is exposed in the low hills of south Sylhet. Between the Someswari river in the Garo Hills district and Jaintiapur, the outcrop of this stage is interrupted by alluvium, but along the foothills forming the northern flank of the Surma valley it has been traced eastwards into Manipur. In north Cachar the beds include many prominent and lenticular sandstones. Near Lumding, the Surma series is probably no thicker than 2,500 or 3,000 feet and, in Evans' opinion, is represented solely by the Bhuban stage. Here the base is often a conglomerate composed mainly of large sandstone boulders in a ferruginous, sandy matrix. Among the rest of the beds, which form a well-bedded sequence, are many calcareous concretions passing sometimes into thin bands of calcareous sandstone ; a thick ferruginous conglomerate within these beds is regarded as a local intra-formational unconformity. In the Dhansiri valley the Boka Bils are seen overlying the Bhubans. In the southern part of the Mikir hills, they are described as resting on various horizons of the Barail series, on the Kopili and Sylhet Limestone stages of the Jaintia series, or even on the ancient metamorphic floor ; the basal conglomerate is said to be best developed where the Barail sandstones are the underlying rocks. In the Naga Hills, part at least of the Boka Bil stage appears to pass laterally as well as vertically into the Tipams so that, when traced northwards, the Boka Bil type of lithology can only be discerned in the lower part of what corresponds to the stage as defined in the Surma valley. Possibly further discoveries of fossils will enable us to draw a true chronological boundary but for the present it is simpler to accept a provisional boundary separating a Boka Bil from a Tipam facies. Rocks of the Boka Bil lithology are still recognisable in the Dayang valley and include thin beds of coarse ferruginous sandstone as well as sand-rock and sandy shales. The maximum thickness of the Boka Bil beds, recognised as such, in the Naga Hills district is 700 feet, but this figure applies to a facies and not to a true stage.

In the Garo Hills two fossil localities have been discovered by Pinfold, one just to the north of Dalu and the other at Bagmara, 30 miles to the east near the Someswari river. In each case the rocks are blue-grey shales with harder sandy beds, associated with Tipam-like sandstones, and belonging in all probability to one and the same horizon in the Boka Bil stage. To the north of these occurrences the beds are described as being almost horizontal or dipping very gently southwards for long stretches, with narrow zones of steep dips ; the fossil beds are found in the most southerly zone of steep dips, where the rocks turn over along the southern edge of the Shillong plateau. More than 100 species have been determined by

Messrs. Vredenburg, Eames and Mukerjee, most of the forms being common to the two localities[107] :

FORAMINIFERA.

Rotalia bessarii (Linn.).

ALCYONARIA.

Paracyathus cf. *cœruleus* Dunc

LAMELLIBRANCHIATA.

Nucula alcocki Noetl.,
Leda (Nuculana) virgo (Mart.),
Lucina pagana Noetl.,
Lucina cf. *d'archiaciana* Noetl.,
Diplodonta (Taras) rotundata (Mont.),
Diplodonta (Taras) incerta (d'Arch.),
Tellina protostriatula Noetl.,
Tellina indifferens Noetl.,
Tellina (Apolymetis) grimesi (Noetl.).
Psammobia (Gari) kingi (Noetl.),
Donax (Hecuba) protoflexuosa (Noetl.),
Solen (Ensis) sp.,
Mactra protoreevesii Noetl.,
Mactra (? Heteromactra) cf. *grateloupi* Desh..
Cardium (Trachycardium) protosubrugosum Noetl.,
Cardium (? Trachycardium) minbuense Noetl.,
Crassatella (Eucrassatella) rostrata (Lam.),
Venus (Omphaloclathrum; Antigona)puerpera Linn., var. *granosa* (Sow),
Venus (Timoclea) subspadicea (Cossm.),
Venus (Clementia) papyracea (Gray).,
Macrocallista erycina (Linn.) (possibly equivalent to Noetling's "*Cytherea erycina*", which has been recorded in this work as *Meretrix (Cytherea) promensis* Theob.),
Meretrix (Tivela) protophilippinarum Noetl., (*Dione* ; *Hysteroconcha*).
Meretrix (Pitar) sp.,
Dosinia subpencillata Vred.,
Dosinia protojuvenilis Noetl.,
Arca (Trisidos) semitorta (Lam.),
Arca (Barbatia) bataviana Mart., var. *carinata* Noetl.,
Arca (Anamalocardia) yawensis Noetl.,
Arca (Anadara) garoensis Muk.,
Arca (Anadara) craticulata (Nyst.), (equivalent to Noetling's *Arca (Anamalocardia burnesi)*,
Arca (Anadara) daviesi Muk.,
Arca clathrata Reeve, var. *birmanica* Vred.,
Parallelipipedum prototortuosum Noetl.,
Tapes (Callistotapes) protolirata Noetl.,
Pinna (Atrina) cf. *vexillum* Born.,
Anomia cf. *ephippium* Linn.,
Placuna (Indoplacuna) sindiensis Vred.,
Chlamys senatorius (Gmel) (very close to, perhaps identical with *Pecten kokenianus* Noetl.),
Chlamys jamviniensis Cox,
Ostraea latimarginata Vred.,
Ostraea papyracea Noetl.,

[107] Rec. 51, 303-336 (1929) ; Gen. Rep. Rec. 62, 23-25 (1929) ; Pal. Ind., New Ser. Vol. 28. No. 1 (1939).

Ostraea cf. *hyotis* (Linn.),
Corbula tunicosulcata Vred.,
Corbula socialis Mart.

GASTROPODA.

Solarium (Architectonica) perspectivum (Linn.)
Solarium (Architectonica) cf. *nitens* (Noetl.),
Torinia buddha Noetl.,
Calyptraea rugosa Noetl.,
Calyptraea chinensis (Linn.),
Capulus lissus Smith,
Natica pellis-tigrina Chemn.,
Natica ala-papilionis Chemn.,
Natica helvacea Lam.,
Natica cf. *vitellus* (Linn.),
Natica epiglottina Lam.,
Natica cf. *didyma* (Bolt.),
Natica coxi Muk.,
Sigaretus (Sinum) protoneritoides (Vred.),
Sigaretus (Sinum) cf. *cymba* (*Menke*),
Sigaretus laevigatus Lam.,
Turritella (Torculoidella) angulata Sow.
Turritella noetlingi Vred.,
Turritella heberti, var. *garoensis* Muk.,
Turritella pinfoldi Vred.,
Vermetus cf. *javanus* Mart.,
Rostellaria (Tibia) cf. *protofusus* Vred.,
Rimella subrimosa d'Orb.,
Cassis cf. *birmanica* (Vred.),
Semicassis cf. *denseplicata* Mart.,
Cassidaria (Galeodea) cf. *echinophora* (Linn.),
Pyrula (Ficula) condita (Brongn.),
Ranella (Gyrineum) tuberculata (Risso),
Ranella (Gyrineum) bituberculata (Lam.),
Ranella nobilis Reeve,
Ranella (Apollon; Bursa) elegans (Beck),
Tritonirdea (Cantharus) martiniana (*Noetl.*), (Noetling's "*Cancellaria martiniana*"),
Latrunculus (Eburna; Babylonia) pangkaensis (Mart.).
Latrunculus (Eburna; Babylonia) cf. *zeylanicus* (Lam.),
Latrunculus (Eburna; Babylonia) lutosus Lam.,
Hindsia (Nassaria) birmanica (Vred.) (Noetling's "*Cancellaria davidsoni*"),
Hindsia (Nassaria) neacolubrina (Noetl.),
Hindsia (Nassaria) cf. *javana* (Mart.),
Nassa (Nassarius) ovum (Mart.),
Siphonalia (Kelletia) subspadicea Vred.,
Murex (Chicoreus) longanensis Mart.,
Clavilithes (Cyrtulus) seminudus (Noetl.),
Vasum cf. *basilicum* (Bellardi).
Melongena (Pugilina) praeponderosa Vred.,
Mitra granatinaeformis Mart.,
Mitra chinensis Gray, var. *subscrobiculata* d'Orb.,
Mitra (Chrysame) cf. *sowerbyi* d'Orb.,
Marginella (Cryptospira) birmanica Vred.,
Oliva (Strephona) australis Ducl.. var. *indica* Vred.,
Olivancillaria (Agaronia) nebulosa Lam., var. *pupa* Sow.,
Ancilla (Sparella) birmanica Vred.,
Cancellaria cf. *birmanica* Vred.,
Cancellaria (Bivetopsia) dertonensis Bellardi,
Terebra (Myurella) protomyuros (Noetl.),

Terebra (*Myurella*) *reticulata* Sow.,
Terebra (*Myurella*) cf. *birmanica* Vred.,
Terebra (*Myurella*) cf. *intermedia* Vred.,
Terebra (*Duplicaria*) *protoduplicata* Noetl.,
Terebra (*Duplicaria*) *woodwardiana* Mart., var. *mindegyiensis* Vred.,
Terebra (*Duplicaria*) *maunguensis* Vred.,
Pleurotoma (*Turris*; *Gemmula*) *congener* (Smith), var. *mekranica* (Vred.),
Pleurotoma (*Turris*; *Gemmula*) *birmanica* (Vred.),
Pleurotoma (*Turris*; *Gemmula*) cf. *thyrsus* (Vred.),
Pleurotoma (*Turris*) *garoensis* (Muk.),
Surcula (*Turricula*) *promensis* (Vred.),
Surcula (*Turricula*) *promensis* (Vred.), var. *silistrensis* Vred.,
Drillia cf. *protointerrupta* Noetl.,
Drillia *protocincta* Noetl.,
Drillia (*Brachytoma*) *tjemoroensis* Mart., var. (probably the same variety as that found in the Kama stage of the Burmese Pegu),
Drillia (*Crassispira*) *cotteri*, var. *decemcostata* Vred.,
Clavatula (*Perrona*) *birmanica* Vred.,
Clavatula (*Perrona*) *birmanica* Vred., var. *singuensis* Vred.,
Calliostoma *promense* Vred.,
Conus (*Lithoconus*) *odengensis* Mart.,
Conus (*Lithoconus*) *ineditus* Mich.,
Conus (*Lithoconus*) *ineditus* Mich., var. *avaensis* Noetl.,
Conus (*Lithoconus*) *decollatus* Mart.,
Conus (*Lithoconus*) *kyudawonensis* Vred.,
Conus (*Leptoconus*) *vimineus* Reeve,
Conus (*Leptoconus*) cf. *bonneti* Cossm.,
Conus (*Dendroconus*) cf. *loroisii* Kien.

SCAPHOPODA.

Dentalium junghuhni Mart.

CEPHALOPODA.

Aturia aturi (Basterot).

CIRRIPEDIA.

Balanus (*Chirona*) *sublaevis* Sow.

DECAPODA.

Calianassa birmanica Noetl.

PISCES.

Carcharias sp.,
Myliobatis sp..

REPTILIA.

Gharialis sp.

This fauna has been correlated with that of the Pyalo stage of the Burmese Pegu, on account of the presence of the type fossil *Ostraea latimarginata* and of *Terebra maunguensis* and *Turritella pinfoldi*, but P. N. Mukherjee's analysis of the fauna shows that nearly one half of the total number of determined species are found in the Kama stage of the Burmese sequence, and it seems reasonable to infer that the Dalu-Bagmara fauna of Assam occupies a position intermediate between the Kama and Pyalo faunas. (Acquitanian-Burdigalian).

Oysters and other marine shells are recorded by F. H. Smith in the Mikir Hills, from what is described as the "Mikir Shale series", perhaps the equivalent of the Boka Bil stage.[108] Some fossil shells found by R. D. Oldham in the Diphupani gorge near Samaguting are said to be identical with some of the Veneridae from strata near Prome in Burma; the beds from which they were collected were assigned to the Tipam series but quite likely represent some portion of the Surma series.[109] Some lamellibranchs discovered by Hayden in the Dayang valley a little further north may also have come from Surma beds, although they were included at the time in the Tipams.[110]

North of the Dayang the Surma series is reduced from 3,000 to 1,000 feet in a horizontal distance of 4½ miles. Twelve miles further north it is not seen, being overlapped by the Tipams, which here rest on the Coal Measures, but in the Dikhu section of the Nazira coalfield the Surma series reappears, consisting mainly of conglomeratic sandstones with shales. It is not found in the vicinity of Jaipur, either in the Disang or the Dihing river sections, where again the Tipam beds are in direct contact with the Coal Measures (Barails). Between Ledo and the Namphuk river the Tipams are seen in the Likha, Tipang and Namchik valleys to be separated from the Coal Measures by nearly 2,000 feet of beds closely resembling the Surmas and consisting of grits, thick conglomerates and a large proportion of argillaceous rocks in the form of shale, shaly sandstone, sandy shale, sandy mudstone and clay; beds of moderately coarse sandstone are not wanting and a little carbonaceous matter is very occasionally present. The beds show rapid lateral variation.

HILL TIPPERA AND CHITTAGONG.

Between Sylhet and the Bay of Bengal, the ranges in Hill Tippera and Chittagong include strata of Upper Tertiary age, some of which have yielded fragmentary marine fossils. These are specifically indeterminable but include small clathrate valves of a *Venus* analogous to *V. vataviana* Mart. such as occur abundantly in the Upper Tertiary of Java and in the Kama beds of Burma.[111]

The Chittagong hill range extends N.N.W.-wards from the town of Chittagong, culminating in the point above Sitakund on which the temple of Chandranath is situated. It is separated from the sea on the west by a narrow strip of alluvium, and from the hills of the Chittagong Hill Tracts to the east by a broad alluvial plain. The range coincides with an anticline overfolded towards the west and with a recognisable crest, exposing two groups of beds, the lower probably corresponding to the Surma series (Boka Bil stage) of Assam and the upper to the Tipams.

[108] Mem. 28, 84 (1898).
[109] Mem. 19, 228 (1883).
[110] Rec. 40, 291 (1910).
[111] E. Vredenburg, Rec. 51, 333 (1920).

The lower group, of which about 3,500 feet are exposed east of the crest at Baraiyadhala, consists almost entirely of shale, the monotony of which is relieved by occasional bands of ill-bedded sandstone or of mixed sediments.[112] Some of the shale, especially in the lowest horizons, shows concretionary structure; here and there it is of an intense blue colour. Among the few fossils found are the following: *Ostraea digitalina* Eichw. (Noetling's *O. promensis*), *O. gryphoides* Schloth (Lamarck's *O. crassissima*), many plates of *Balanus*, a broken shark's tooth, and indeterminable fragments of *Arca. Pecten, Trochus, Oliva* and corals. The fossils occur in comminuted fragments in a hard conglomeratic ragstone or in a very hard shell-limestone. The two species identified are typical Pegu forms. Gas but no oil seepages occur; considerable quantities of the former have been encountered in borings.

Mud volcanoes are known to exist further north at the foot of the Tippera hills on the eastern boundary of the Tippera district, sixteen miles due north of Commilla.[113]

MAYURBHANJ.

Probably belonging to the Assam gulf and occurring at the mouth thereof are some Tertiary strata discovered by P. N. Bose in Mayurbhanj (Mourbhanj) State, underlying the laterite which along the neighbouring Orissa coast forms an almost continuous belt. The beds, first found at Molia, in the bed of the Barabalang river, two miles south of Baripada, the capital of the State, comprise yellowish and yellowish brown limestones, very rich in specimens of *Ostraea*, passing up into greyish or very pale green clays. Clays of this kind, horizontal or with a slightly rolling dip, are seen in all sections around Baripada under a variable thickness of laterite.[114] A boring put down at Baripada reached a depth of 163 feet without finding the base of the Tertiary beds. About tow-thirds of the beds passed through consisted of bluish clay, one or two beds of it carbonaceous; the rest of the section was made up of brownish sandstone at the top, and four or five thin bands of fossiliferous limestone, marl, gritty clay or sandstone intercalated amongst the clays.[115]

Among the fossils are fragmentary lamellibranchs, but the only two species so far identified are a *Rotalia* very close to *R. beccarii* Linn., an indifferent form for stratigraphical purposes since it ranges from the Jurassic to the present day[116] and *Ostraea* (*Crassostraea*) *gajensis* Vred., a Gaj species. F. E. Eames, who has identified the latter, refers the beds to the Gaj.[117]

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[112] E. H. Pascoe, Mem. 40, 311 (1914)
[113] G. S. I. Notes, Rec. 30, 111 (1897)
[114] P. N. Bose, Rec. 31 137 (1904).
[115] P. N. Bose Rec. 34, 42-44 (1906).
[116] G. H. Tipper, Rec. 34, 135 (1906).
[117] Gen. Rep. Rec. 69, 20 (1935); Rec. 71, 150-151 (1936). Vredenburg records "*Ostraea orissensis*", from the Orissa coast and closely related to an undescribed species in the Upper Gaj (Gen. Rep. Rec. 41, 63 (1911)).

Bose has expressed the opinion that these fossil beds will eventually be found also in the contiguous district of Midnapore, under the laterite.

PURI.

Waterworn specimens of a lamellibranch picked up on the foreshore at Puri, further down the Orissa coast and 160 miles from Baripada, have been referred by M. R. Sahni to the genus *Paphia*, and are closely comparable with so-called *Tapes gregaria* Partsch from the Sarmatian of Austria.[118] The matrix infilling one shell was a brownish compact sand, and that in another a bluish clay. There is reason, therefore, to suspect the presence of Tertiary rocks, perhaps similar to those found in Mayurbhanj, under the alluvium of the Puri district.

THE DURGAPUR BEDS OF THE DAMODAR VALLEY.

The age of the youngest pre-Alluvial beds in the Damodar valley has so far eluded determination, but may be equivalent to that of the Dubrajpur beds found in the Rajmahal hills and already described as part of the Upper Gondwana succession. The possibility of their Miocene age, however, must not be forgotten. The presence of dicotyledonous fossil wood appear to be in harmony with such an idea, but the provenance of the remains is now though to be the older Gangetic Alluvium which overlies the Durgapur beds, and not the Durgapur beds themselves.[119] The nature of the thin coal band in so far as it shows a higher percentage of volatiles than of fixed carbon favours a Tertiary age.[120] It is therefore possible that the Durgapurs represent estuarine deposits of the Miocene sea, the transgression of which must have been close to the eastern end of the Raniganj area.

Whatever their age may be, the pebbly sandstones of this stage are found overlying the Panchet beds in some of the coalfields of the Damodar valley. Such beds are seen resting at intervals on the Upper Panchets along the southern edge of the Raniganj field, occupying the upper portions of Panchet, Goranji and Biharinath hills. They are described as a series of coarse, pebbly sandstones with subordinate clays of a dark red colour. The sandstones are friable, massively developed, sometimes current-bedded, and often include numerous rounded or sub-rounded pebbles consisting largely of quartzite ; some of the medium textured sandstones are ferruginous and felspathic. A few imperfect plant remains have been noted in the clays. In the Raniganj area the dip of these beds increases to about 12° as the southern boundary of the field is approached. The distribution of the beds of this stage indicates a hiatus between them and the Panchets on which they lie, but the junction with the latter is rarely visible. On both Panchet and Biharinath hills where the Durgapur beds lie almost horizontally, at least 1.000 feet and possibly as much as 1,200 feet of the beds have survived weathering.

[118] Rec. 68, 418 (1934).
[119] Gen. Rep. Rec. 62, 144-145 (1929).
[120] E. R. Gee, Mem. 61, 70 (1932).

CHAPTER XXXII.

TERTIARY (CONTINUED)—THE OLIGOCENE-MIOCENE SEQUENCE IN BURMA.

The general character of the Pegu series; Distribution; Vegetation; Cone-in-cone structure; Efflorescent salt; Stratigraphical limits; Lateral variation; Thickness; Subdivision. **The oilfields of Burma and adjacent Pegu inliers**: Yenangyaung; Yenangyat-Singu; Pegu and Gwegyo; Minbu; Inliers in Myingyan, Magwe and Thayetmyo; Shinmadaung; Ingyin Taung and Powin Taung; Indaw; The Lower Chindwin district; Provenance of the oil. **The stages of the Pegu series**: Foreign equivalents; The Lower Pegu: The Shwezetaw stage; The Padaung stage; The Sitsayan Shales of Prome and Henzada; The Singu stage; The Lower Prome stage; The Singu stage. The Upper Pegu: The Kama stage: The Upper Prome stage; The Kama of north Minbu; The Kama stage in the Yenangyaung and Singu oilfields; The Kamas of Pakokku and Myingyan; The Pyalo stage; The Akauktaung stage; The White Sand and Red Bed. **Northern Exposures of the Pegu.** The Pegus of the Pegu Yoma. The Arakan Coast. The Andaman Islands. **Palaeogeography in Oligocene-Miocene times.**

THE GENERAL CHARACTER OF THE PEGU SERIES.

Distribution.—In Burma the Oligocene and Miocene are represented by the Pegu series, a formation which now covers a large area and was deposited in a long N.-S. gulf between the Shan highlands on the east and the Arakan Yoma and Chin Hills on the west. Northwards the series is exposed in the eastern part of the Lower Chindwin district, and has been traced into the southern borders of Upper Chindwin but its ultimate limits in this direction are not yet known. The Pegu basin attains a maximum width of a little over 100 miles in the latitude of Meiktila, becomes slightly constricted to about 85 miles across Prome and Toungoo, broadens again slightly further south but soon becomes largely concealed by Recent deposits which entirely replace it beyond Rangoon. The most southerly occurrence of Pegu rocks is seen in a small inlier at the northwest corner of the Hlawga Reservoir, some twenty miles north of Rangoon.[1]

The Pegu series forms a wide continuous outcrop between the Irrawaddy and Sittang rivers from Rangoon to a point fifteen or sixteen miles west and a little south of Mandalay. It is also exposed amid the younger Irrawadian sandstones in numerous anticlinal or dome-shaped inliers, of which some have proved to be oilfields of importance.

Vegetation.—The characteristic trees of the Pegu outcrops are the *sha* (*Acacia catechu*), the *kyun* (*Tectona grandis*) and the *myinwa* *Dendroclamus strictus*); other common trees on the Pegus of the Prome area, are the *naba* (*Odino wodier*), the *zi* (*Zizyphus jujuba*) and the *didu* (*Bowbax insigne*). The *in* and the *ingyin* (*Dipterocarpus tuberculatus* and *Pentacme suavis*, respectively), so typical of Irrawadian country are not usually found on Pegu exposures.

[1] Gen. Rep. Rec. 65, 96 (1931).

Cone-in-cone structure.—Cone-in-cone structure is not uncommonly seen in the sandy shales of the Pegu series. This was at one time thought to be an effect of the upward escape of gas, of which the Pegu series in places contains enormous volumes. One of the latest suggestions is that it is a result of contraction, settling or volume-shrinkage during the slow dewatering of highly saturated, porous, fine-grained sediments of any kind deposited in a loosely packed condition.[2]

Efflorescent salt.—A highly characteristic feature of Pegu outcrops, and one which is not usually shared by the more porous Irrawadian strata, is the presence of a white efflorescence of impure sodium sulphate in dried or half-dried stream-beds and marshy places. This *reh*, as it has been called in India, has been produced probably by the action of sodium carbonate, a salt always present in earth water—upon the calcium sulphate which, in the form of gypsum, is so plentiful in the Pegu formation; a parallel character is the saline and sulphatic nature of the water in these beds. The efflorescence, when sufficiently rich in carbonate, is used as soap-sand-*sapaya*—for the laundering of clothes, especially in the Lower Chindwin and Sagaing districts;[3] some 3,882 tons were produced in Burma in 1933.[4] Brine, derived probably from Pegu and other Tertiary strata has been utilised in the production of salt in the Amherst, Arakan, Shwebo and Sagaing districts, and in the Hukawng valley; in Sagaing and Shwebo it is obtained from hand-dug wells, most probably from the Pegu.[5] The composition of the brine varies largely from place to place,[6] the chief impurities from the standpoint of a sodium chloride yield being calcium chloride, calcium sulphate and magnesium chloride.[7]

Stratigraphical limits.—It is possible that the "Nummulitic" division of Theobald transgressed upwards to some extent into the Oligocene, *i.e.*, into beds which we now class as Pegu; no unconformity was detected between the "Nummulitic" and the overlying beds, and it was admitted that some of the Nummulitic shales greatly resembled the lowest stage of the Pegus (Sitsayan shales) except that they were somewhat darker in colour. Over the upper limit of the Pegu series there has also been some dispute, which has been settled according to an agreed convention. The confusion into which the subdivision of this thick formation was for many years thrown by Noetling's classification has been gradually remedied by the work of the Burma Party of the Geological Survey of India, and mainly by the efforts of G. de P. Cotter based on the palaeontological revisions of the late E. V. Vredenburg. As now defined, the Pegu of the central and southerly portions of Burma is the close equivalent of the combined

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[2] B. M. Shaub. Amer. Journ. Sci., Ser. 5, Vol. 34, 331 (1937).
[3] Gen. Rep. Rec. 62, 67 (1929).
[4] 'Mineral Production', Rec. 70, 440 (1936).
[5] Gen. Rep. Rec. 62, 63 (1929).
[6] Gen. Rep. Rec. 65, 94 (1931).
[7] Gen. Rep. Rec. 65, 64 (1931).

Nari and Gaj of western India. Between the Oligocene and Miocene portions of the series an unconformity has been drawn by G. W. Lepper, and it is possible that discordance at this horizon is somewhat more widespread than it is between some of the other stages. Local unconformity is a common feature in the Pegus of Upper Burma, and cases of "intercalated contortion," due to local in competence of the beds along certain horizons, is observable in most of the anticlinal inliers. Several of the latter are partially, a few of them wholly, bounded by faults.

Lateral variation.—Traced northwards the Pegu beds show evidence of shallower and shallower water conditions. Silicified wood, which is rare in south Minbu is found in the Ngahlaingdwin anticline of north Minbu and becomes abundant in Pakokku; in the latter district the Pegu sandstones simulate the current-bedding of the fresh-water Irrawadian sandstones. Many of the beds, when traced northwards, after passing through the current-bedded sandstone phase, end up as red earth beds or ferruginous conglomerates indistinguishable from members of the Irrawadian series. The poorly developed Upper Pegu of north Minbu and Pakokku is characterised, according to Cotter, by many local fresh-water or very shallow-water marine beds, more or less barren of fossils, and by many breaks in deposition;[8] in these latitudes there is no trace of the rich Miocene fauna found in the Upper Pegu Thayetmyo.

Such lateral changes introduce a quandary with regard to mapping, which has no really satisfactory practicable solution. In the case of a single outcrop of intermediate position, showing the marine fossiliferous facies in the south and the practically unfossiliferous estuarine or fresh-water facies in the north, it is possible to trace the boundary lines drawn in the south into the unfossiliferous northern end of the exposure. This has been actually done by Cotter in the Pakokku district. Further north, however, in outcrops with no trace of the marine facies and no fossil bands to control such a proceeding, subdivision must be not only largely lithological but cannot synchronise with that adopted further south. As an example of the problem involved, we may take the Akauktaung stage which from a chronological point of view, almost certainly represents a considerable portion of the lower Irrawadian. In its type area, however, it contains marine fossils and in facies is a continuation of the Pegu. In the type area it would be a simple matter to map it as a marine facies of the Irrawadian—which it really is—and to draw the Pegu-Irrawadian boundary at its lower limit; this was in fact the original procedure. In Upper Burma, however, these beds are represented by fluviatile sediments with a totally different and scanty fresh-water fauna which it is impossible to correlate with the marine Akauktaungs; in any case to indicate its upper and lower boundaries in this part of Burma would be impossible, especially as more and more of the marine beds beneath take on a similar fresh-water facies as we go north. As representing the only practicable method of subdivision, therefore,

[8] Mem. 72, 76 (1938).

the boundaries have been mapped on a taxial and not on a chronological basis, on the understanding that the difference between the two may be very considerable. The Pegus of north Burma, mapped in this way, were not deposited between the same time limits as were those in the south. In other words, as the Irrawaddy-Chindwin gulf became gradually silted up with sediment brought down mainly from the north the sea retreated southward, giving place gradually to river sediments. It is this marked lateral variation, consequent on the length of the gulf, which is responsible for the wide discrepancies in the correlation adopted by various authorities.[9]

Thickness.—Of the extent to which the thickness of the Pegu varies we know very little, since there are so few complete sections of the series. In the Ngape area of south Minbu there are over 12,000 feet of Pegu beds, and of these 4,000 feet belong to the Lower division or Nari (Oligocene). In north Minbu upwards of 14,000 feet of Pegu strata are exposed, on the authority of Cotter, of which the lower 8,500 feet belong to the Oligocene, while the upper 5,500 feet represent a shallow-water facies of the Miocene.

Subdivision.—The Pegu series has been subdivided into the following stages, the boundaries of which are frequently vague and variable, especially those of the higher stages. These stages are recognised mostly by their respective faunas, the change vertically from one to the other being gradual, as might be expected ; here and there occur fossil horizons intermediate in character between the faunas of two stages.

The following tables give the classification and correlations of Pegu, done by Holland who combines Vredenburg's correlations with the results obtained by G. de P. Cotter in Upper Burma and by E. L. G. Clegg respectively.

------		Burma.	Java.	Western India.
Lower Miocene.	Pontian.	Akauktaung.	Odeng.	Talar.
	Vindobonian	..	Tji Lanang.	Upper Gáj.
	Burdigalian.	Pyalo.	Njaligdum.	
	Aquitanian.	Kama.	Rembang.	Lower Gáj.
Oligocene.	Chattian.	Singu	Not identified.	Upper Nari.
	Stampian.	Padaung.		Lower Nari.
	Lattorfian.	Shwezettaw.		Mula pass limestones.

[9] As an example, while some would equate both the Surma and Tipam series of Assam with the Upper Pegu of Burma, and the Dihing series of the former region with the Irrawadian of the latter (G. W. Lepper. World Petrol. Congr. Lond., Vol. I, 15-25 (1933), others maintain that the Irrawadian of the extreme north of Burma and the Tipams of Upper Assam are equivalent. Such divergency is more apparent than real if the Irrawadian of north Burma corresponds in age to the Upper Pegus of the south.

Correlation of the Pegu System at Prome, Kama, in Western Thayetmyo and in North Minbu.

Prome Latitude (18°50′)	Kama (Latitude 19°02′).	West of Thayetmyo (Latitude 19°20′).	North Minbu (Latitude 20°25′).	Burma Oil Company nomenclature. (Probable correlation with).	Stage.
Prome Sandstones.	Upper Sandy Series.	Upper Sandy Series.	Upper Sandy Series.	Obogon Alternations.	Helvetian Tortonian.
				Kyaukkok sandstones.	Burdigalian (includes Prome Sandstones).
Sitsayan Shales.	Kama clays.	Kama clays of Padaukpin.	Shale series of Shasibu *chaung*.	Pyawbwe clays.	Aquitanian.
	Middle Sandy Series east of Kyaukme.	Okhmintaung ridge and Monetkon sandstones.	Middle Sandy Series.	Okhmintaung sandstones.	Chattian.
	Padaung clays of Kyaukme.	Padaung clays of Tiyo valley.	Padaung clays.	Padaung clays.	Stampian.
	Shwezetaw sandstones (weakly developed).	Shwezetaw sandstones (weakly developed).	Shwezetaw sandstones.	Shwezetaw sandstones.	Lattorfian.
Eocene	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.

Dudley Stamp records a fauna, found in several parts of central Burma and regarded by him as intermediate between the Singu and Kama faunas. To the beds containing it he has given the name of Migyaungye stage but Clegg considers an interpolated stage unnecessary.[10] The number of stages into which it is advisable to split the Pegu is a matter purely of convention and convenience. Fossils occur at a large number of different horizons throughout most of the normal Pegu succession and the fauna of each stage shows progressive variation from its base to its summit; it would probably be easy to find, for instance, examples of faunas intermediate between other pairs of the stages established and enumerated above.

THE OILFIELDS OF BURMA AND ADJACENT PEGU INLIERS.

All the stages mentioned above are exposed along the eastern flank of the Arakan Yoma and its northward continuation, the Chin Hills. Before describing them in detail, it is proposed to deal with certain aspects of the more important exposures of Pegu rocks in the Irrawaddy valley, some of which have achieved fame as oilfields.

Yenangyaung.—The best known and richest oilfield is that of Yenangyaung (*ye-nan*=oil; *gyaung*=place). The beds have yielded some crushed and dwarfed fossils, which give indications that they belong for the most part to the Kama stage of the Pegu. (see p. 1720). The crest of the anticlinal dome, on which this well known oilfield is situated, lies two miles east of the Irrawaddy bank at Yenangyaung, in the Magwe district. The inlier of Pegu rocks is just under six miles long and a little over one mile across its greatest breadth, and is surrounded by Irrawaddy Sandstone. It is the central portion or kernel of this oval inlier which constitutes the oilfield. The prevailing rocks are mixtures of sand and clay or alternating laminae of the same. Sand predominates over clay, calcareous sandstones are rare and thin, and there is more inter-mixing and current-bedding than usual in neighbouring Pegu exposures; all this is evidence of a shallow-water facies and estuarine conditions, and some of the beds are obviously but precursors of the Irrawadian. Carbonised wood and selenite occur in the lowest exposed horizons, and cone-in-cone structure has been noted in the upper most.[11] Veins and pipes of mud, especially in the more southerly half of the inlier, witness to the former existence of mud volcanoes or salses.

The dome which includes the Pegu inlier is an integral part of an anticlinal fold extending along the east bank of the river, in a general N.N.W.-S.S.E. direction, for over forty miles. In ordinary parlance the fold would be described as symmetrical, but the slight departure from perfect symmetry observable at the surface has been found by the Burmah Oil Company's borings to be intensified underground, the result being that the somewhat greater steepness of the

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[10] Journ. Burma, Research Soc., Vol. 17, 117-189 (1927); Mem. 72, 146 (1937).

[11] E. H. Pascoe, Mem. 40, 57, 58 (1912).

western limb has thrown the deeper oil-pools a little towards the east.

The inlier is affected all round its margin by a large number of faults which, in the great majority of cases of negligible size and importance individually, are of considerable interest from the manner in which they display the adaptation of the fold to the compressional force which produced it.

The exploitation of oil at Yenangyaung dates back a great number of years, possibly to the latter part of the 13th century. The native method of sinkink hand-dug shafts is of extreme interest but cannot be described here in detail. With the aid of a diver's outfit, depths of over 400 feet have been attained in this primitive fashion. Such methods have been almost entirely superceded by mechanical boring, and one oil sand after another has been reached, without any indication so far of an end ; oil and gas have been met so far down to depths below 5,000 feet. The most noteworthy features of this field are its long life compared with its small size, the number of different oil horizons, and the extraordinary concentration of the oil supply within an area of about 1½ square miles, by far the greater part of it having been derived from an area of less than one square mile. Between the year 1888, when boring first commenced, and 1938, inclusive, the total oil supplied by this small area was 5,447,454,560 gallons. The production is now on the decline. The bulk of the oil is gassy, with about 15 per cent. of naphtha and nearly the same proportion of solid paraffin. The oil sands appear to be old sandbanks and show some irregularity due to their lenticularity, but the richer sands are independent of another.

Yenangyat-Singu.—Next in importance is the Singu oilfield, twenty-five or thirty miles further north in the Myingyan district ; this is a southerly continuation of the Yenangyat field on the other side of the river Irrawaddy. The Yenangyat hills are a long, wild and picturesque range, skirting the right bank of the Irrawaddy in the Pakokku district and separating this river from its tributary the Yaw ; southwards they are cut through obliquely by the Irrawaddy, the southerly continuation on the left bank of the river being known as the Singu hills, which sink gradually southwards into the plateau. The hills are occupied by a long inlier of Pegu beds, cropping out from beneath the Irrawaddy Sandstone, as at Yenangyaung, and the structure is that of a single asymmetric anticlinal fold which rises and pitches, producing three local dome structures or crest-maxima, each of which forms a separate oilfied. While the western limb is gently inclined. The eastern is steep, often vertical or overfolded. The axis is not continuous with that of Yenangyaung, but lies on a line about eight miles further east.

The beds, more constant in character than they are at Yenangyaung, belong to the Padaung, Singu and Kama stages (see p. 1689). The length of this Pegu inlier is just under 39 miles, its maximum width being about 3½ miles. The thickness of the Pegu exposed to

the east of the crest is always considerably less than that of the beds on the western side which attain a maximum of about 3,740 feet. At the Singu end of the fold, where in the latitude of Chaukywa the thickness west of the crest is 2,400-2,450 feet in contrast to 1,450 feet on the east side, the missing beds have been shown by S. R. Rau to be the uppermost Pegus. This discrepancy which amounts in places to as much as a difference of over 3.000 feet, may be partly explained as the result of fold faulting, *i.e.*, faulting accompanied by severe attenuation of the strata. It is, however, not at all unlikely that the discrepancy has been considerably enhanced by local erosion of the Pegu sediments by an early precursor of the present river, before the deposition of the fluviatile deposits so aptly designated the Irrawadian. This suggestion receives some measure of support from the occurrence of Pegu debris in the basal Irrawadian along the eastern contact.

The most valuable dome structure from an oil-winning point of view is that of Singu, which is continued for some miles across the river under the name of the Lanywa field. In comparison with the Singu-Lanywa field the fields of Yenangyat and Sabe, further north, have proved of very minor importance, partly perhaps because some of the rich Singu sands have been exposed by denudation in the two more northerly crest maxima. Three of the Singu fossil beds have been traced into the Yenangyat area, the lowest one of them, the *Dendrophyllia* bed, to within five miles of Yenangyat village; in this way it has been possible to calculate that in the Yenangyat dome centre erosion has laid bare some additional 2.770 feet of strata stratigraphically below the lowest bed in Singu. These lowest horizons belong to the Padaung (Minbu-Yenangyat) stage (see p. 1704).

Pegu and Gwegyo.—The Pagan inlier and what is practicially a southerly continuation thereof, the Gwegyo inlier, lie ten or twelve inliers to the east of the Yenangyat-Singu fold, in the Pakokku and Myingyan districts. The Pagan hills commence about five miles southeast of Pagan and form a conspicuous land-mark for some 14 miles, rising abruptly from a comparatively flat alluvial plain. They are formed of an inlier of Pegu rocks bent into a sharp asymmetric anticline of which the steeply dipping easterly limb has for the most part been obliterated by faulting. Probably both the Padaung (Yenangyat) and Singu stages are exposed, since the outcrop is *en echelon* with the Gwegyo hills to the south, where these two stages are present. The total thickness of Pegu beds in the Pagan hills is between 2.000 and 2.500 feet, consisting of alternations of sandstone and shale, the former predominating except along the centre of the hills which is occupied by deep blue shales.[12] A few streaks of coal have been noted in some of the shales.

The Gwegyo hills have the same N.N.W.-S.S.E. trend and rise as abruptly as the Pagan hills, but are surrounded by an outcrop of Irrawaddy Sandstone. The southern end of the inlier, exposed in

[12] G. E. Grimes, Mem. 28, 66-67 (1898).

more or less sunken relief, has been termed the Payagyigon-Ngashandung oilfield which, however, has met with no appreciable success. In this outcrop which is 23 miles in length, under a capping of hard sandstone, shales predominate and there is much selenite. This asymmetric anticline has also been destroyed by faulting and only westerly dipping beds remain except at the extreme ends where traces of a crest can be seen.

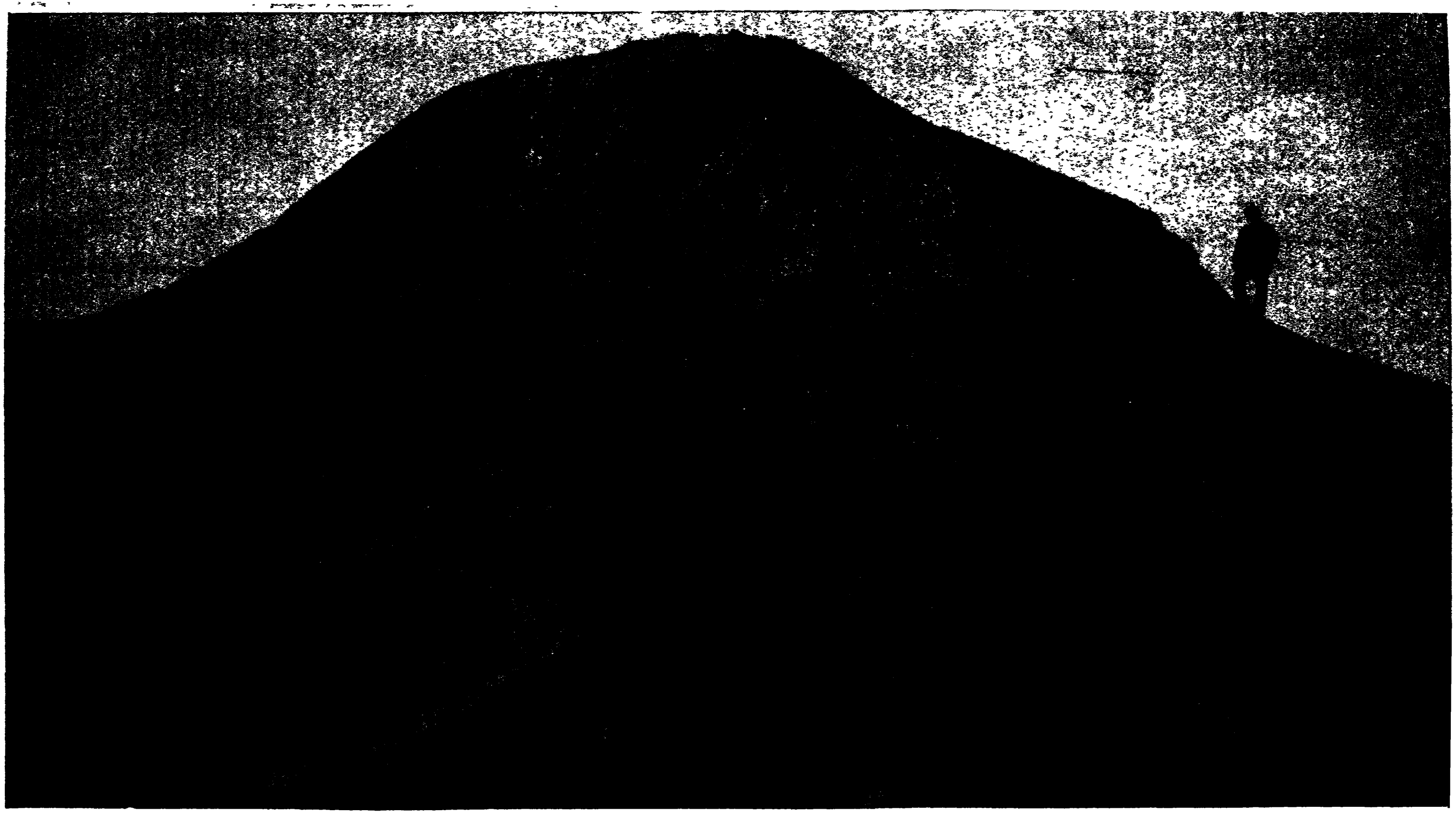
Minbu.—The Minbu outcrop is well known on account of its mud volcanoes, and extends from a little north of Minbu town for several miles in a S.S.E. direction, finally merging into the main tract of Pegu beds which stretch across Thayetmyo to the Pegu Yoma. Like that of Yenangyat, the anticline is asymmetric, but the asymmetry is due rather to irregularities in shape than to the greater steepness of the eastern limb as compared with the western. The beds on the west, in fact, often dip as steeply as those to the east, and the irregularities suggest intermittency of the folding movement.[13] The flexure is sharp and deeply denuded, and has reached a more advanced stage than the Yenangyat fold. The beds exposed belong for the most part to the Padaung (Yenangyat) stage, the higher horizons probably falling within the Singu stage.

The well known "mud volcanoes", always an object of interest to travellers journeying up the Irrawaddy, mostly lie in a straight line along part of a fault in the neighbourhood of Minbu town. The number of vents is immaterial since new ones are always being produced and parasitic cones are constantly making their appearance on the flanks of larger ones. All stages in their formation can be seen from tiny excrescences an inch or two across to conspicuous cones of dried mud ranging up to 80 feet in height above the plain and covering a considerable area. In each of the "active" cones is a "crater" containing liquid mud up which gas and oil percolate. In witness to the age of these mud effusions some of the older cones are covered with gravel. There are also two principal groups of gas pools of bituminous mud in the alluvial plain north of the "volcanoes"; these belong to the same category as the latter and differ only in the fact that the mud formed is not sufficiently viscous to build up a cone. Oil seepages also occur in other sections of the anticline further south. The Minbu fold is the site of one of the minor oilfields of Burma, the compression of the structure and the narrowness of the productive area being the cause of the limitation of oil accumulation.

There is in this fold also a discrepancy between the thickness of the Pegu beds east and west of the crest. This is probably less than it is in the case of Yenangyat and may not be more than 2,000 feet.[14] Here there is no trace of a fault along the eastern boundary, nor can

[13] E. H. Pascoe, Mem. 40, 158 (1912).

[14] The figure of 3,260 feet recorded as the difference in thickness in the latitude of Tat Taung, some eight miles south of Minbu town, may be an exaggeration due to the extreme difficulty of identifying the Pegu-Irrawadian boundary along the western side of the fold.



MUD VOLCANO, MINBU, BURMA.

the difference in thickness be due to erosion and unconformity along this horizon since the *Arca* fossil bed is recognisable a little below this level on both sides. A depositional thinning-out from west to east of this order seems too excessive even in the case of the Pegus, and we appear to be reduced to the suggestion that the discrepancy is due to faulting along the crestal area, or to intra-formational erosion and unconformity.

Inliers in Myingyan, Magwe and Thayetmyo.—The Ondwe inlier, in the Magwe district, lies on or very close to the line of folding of the Yenangyaung oilfield and is only some 30 miles distant therefrom; in spite of this, boring operations here met with gas but no oil. The asymmetric anticline of Pegu beds cropping out amid the Irrawadian sandstones at Kabat in the district of Myingyan, northwest of the Recent volcano of Popa, needs no more than recording. Another Pegu inlier, having the structure of a gentle dome, is seen at Wetchok and Yedwet in the Magwe district.

In the Wetchok-Yedwet dome, about 300 feet of Pegu beds are exposed beneath the Irrawadian. Fossils are frequent but very fragmentary, and occur in thin slabs or flattened spheroidal masses of hard sandy limestone. The lowest fossil bed consists for the most part of *Turritella*—especially *T. angulata* Sow.—and might correspond to the Turritella Sands of Thayetmyo, though this fossil ranges down to the Kama and Singu stages, and its mere presence means little. A very common type of bed in the Wetchok-Yedwet dome, and in other Pegu exposures of Upper Burma, consists of a soft, light-coloured sand containing laminae or elongated lenticles of a bluish or greenish clay; at a suitable distance the combination presents the appearance of a shale. A calcareous clay with cone-in-cone structure occurs a short way below the upper boundary of the Pegu of this inlier.

The highest horizon, near Thamonbin, is composed of an oyster bank of *Ostraea promensis* Noetl., and a few other fossils;[15] in Henzada, as we have seen, this oyster occurs in company with *O. gingensis*, a form which in Sind occurs abundantly in the zone of *O. latimarginata*, the type Pyalo fossil. Evidence as to the precise age of the beds exposed is inconclusive, but the suggestion may perhaps be made that they belong to the Pyalo and upper part of the Kama stages.

A flat-topped, asymmetric anticline, exposing the Kama stage and the Mogaung sands (Akauktaung stage *partim*), exists at Padaukpin in Thayetmyo, with steep dips on the northeast and gentle dips, averaging 20° on the southwest: oil was formerly obtained in shallow hand-dug wells but deep boring has met with no success.[16]

The crushed anticline of Ngahlaingdwin in north Minbu has been described by C. Porro;[17] it is characterised by oil seepages and there are a few hand-dug wells.

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[15] E. H. Pascoe, Rec. 36, 291 (1907).
[16] E. H. Pascoe, Mem. 40, 171 (1912).
[17] Rec. 45, 255-259 (1915).

Oil and gas seepages occur in the neighbourhood of Yenanma, some 40 miles northwest of the town of Thayetmyo, where small quantities of oil have been obtained by drilling. About 3¾ miles west of the oilfield is a line of mud volcanoes. The Pegu beds, in the form of an outlier on the Eocene, are all dipping uniformly to the E.N.E. at an angle of about 20°, and there is no evidence of an anticlinal crest. According to Murray Stuart, the oil comes from a thrust-plane which has operated from E.N.E. to W.S.W.; it is regarded by this authority as derived from Eocene lignites and not of Pegu age.[18]

At Pyaye, some eight miles southwest of Thayetmyo town, a small inlier of Pegu rocks, occupying an anticlinal corrugation in the centre of a broad synclinal tract, has yielded enormous quantities of gas. Between the depths of 2,083 and 2,109 feet about 20 million cubic feet of gas per day were given off, while at 2,525 feet the yield was 39 million cubic feet. The roar of the escaping gas could be heard in Thayetmyo.[19]

In the townships of Singbaungwe and Allanmyo in Thayetmyo, crumpled and faulted Pegus are folded into three approximately parallel anticlines with intermediate synclines, striking N.W.-S.E.[20]

Shinmadaung.—The most interesting feature of the Shinmadaung area in north Pakokku is the presence among the Pegu sediments of interbedded ashes and rhyolitic agglomerates.[21] Possibly some of the volcanic rocks of this area are of later age, but some at least are contemporaneous with the Pegu. In the Shinmadaung area the floor upon which the Pegus lie is not exposed;[22] both the Shwezetaw and Padaung stages can be recognised, while some younger unfossiliferous beds are assigned to the Singu and Kama stages, the Pyalos being perhaps represented by some volcanics. In the adjacent Salingyi uplands occur highly metamorphosed dacites, dolerites, epidiorites and coarse diorites as well as a somewhat later granite and pegmatite. These igneous rocks, or at any rate the earlier less acid suite, form in all probability a laccolitic intrusion into the Pegus.

Ingyin Taung and Powin Taung.—Volcanic intercalations are also seen in the Pegus of the Ingyin Taung and Powin Taung area, consisting of andesites, rhyolitic agglomerates and fine-grained ashes and tuffs. The andesites are locally silicified, yielding an amygdaloidal rock having its vesicles filled with chalcedony; the ashes and tuffs are highly metamorphosed to slaty or schistose rocks. Ingyin Taung and Powin Taung are members of a range of hills showing a steep scarp on the west side. The local bed of the Pegus is a distinctive conglomerate, some 4 feet thick, composed of rectangular

[18] Journ. Inst. Petrol. Techn. Vol. 11, No. 52, 475-486 (1925).
[19] C. J. Barber, Mem. 66, 89-90, (1935).
[20] Gen. Rep. Rec. 45, 125, 127 (1915).
[21] Gen. Rep. Rec. 60, 87 (1927).
[22] A. E. Day, Trans. Min. Geol. Inst. Ind., 21, 154 (1927).

and subrectangular fragments of shale in a matrix of soft buff sandstone. This is immediately overlain by a massive sandstone forming the scarp of Ingyin Taung and dying out northwards, where it is replaced by alternating shales and sandstones with occasional lenticles of limestone; this limestone has yielded a rich and unusual fauna which appears to be of Miocene age (see p. 1723). The bulk of the volcanic activity of this and the neighbouring Chindwin regions was post-Pegu, and will be referred to later, but the disturbances commenced in the earliest stage of this series, and those in the Wuntho area may even date from some epoch of the Eocene.

Indaw.—At Indaw in the Upper Chindwin district is another minor oilfield, situated on an inlier of Pegu beds some 18 square miles in area. In this elongated asymmetric dome, with an eastern limb dipping up to 65° and a western with dips rarely exceeding 20°, the exposed beds are predominantly sandy. Gas under high pressure has been encountered in sands below the main oil zone, and the available gas resources, estimated at some 12 million cubic feet *per diem*, so far seem to be more promising than those of oil.

The Lower Chindwin district.—In the northern and central parts of the Lower Chindwin district the Pegus and a part of the Eocene (Tabyin stage) are absent, and inliers of the Pondaung Sandstones are seen directly overlain by the Irrawadian. Either the missing beds were deposited and subsequently removed by erosion before the deposition of the Irrawadian river silts, or else were never deposited at all, the Pondaung beds of this area having formed a land surface soon after their accumulation and having remained so till the present day; of the two alternatives, Sondhi favours the latter and prefers to regard the Irrawadian sediments as having been deposited around islands of the Pondaung beds.[23] In some exposures in the central portion of the district, the Pegus and Yaws appear to be represented by unfossiliferous beds. An inlier of Pegu rocks forms the core of a range northeast of Monywa, in the Lower Chindwin district. The structure appears to be that of an asymmetric anticline faulted along its crest.

Provenance of the Oil.—Many oil seepages other than those recorded above and too numerous to mention, have been reported from time to time in various parts of Burma. They are not confined to the Pegu series but occur sometimes in older formations. The oldest oil manifestations of the Irrawaddy-Chindwin valley belong to the Tabyin Clay (Upper Lutetian) and are found on the borders of the Pakokku and Lower Chindwin districts. In the Ngahlaingdwin anticline of Thayetmyo and in the Myaing anticline of Pakokku the seepages as we have seen, come from the Pondaung and Yaw stages (Auversian and Priabonian respectively of the Eocene); there are also seepages in the Pondaung Sandstones at several places in northwest Pakokku. As Cotter points out, in a condensed and

[23] Gen. Rep. Rec. 62, 104 (1929).

able sketch of the oil-bearing rocks of India and Burma,[24] the petroleum of Burma is found in shallow-water marine beds of alternate shales and sandstones with occasional thin interbedded marls and limestones. It has been suggested by the writer that the oil is derived from vegetable matter, the change, under saline conditions, producing oil instead of coal. Murray Stuart has expressed the opinion that the vegetable remains in question consisted in the main of *Dipterocarpus*, a tree which forms resinous substances on a large scale in its leaves and wood,[25] a dipterocarpus tree has left abundant silicified remains in the succeeding Irrawadian series.

THE STAGES OF THE PEGU SERIES.

Foreign equivalents.—It is now necessary to consider in order the various stages into which the Pegu series has been subdivided, and their particular faunas. Since the lower half of the series probably represents the whole of the Oligocene, with no pronounced unconformity at either the lower or upper limit, the three stages into which it has been subdivided—Shwezetaw, Padaung and Singu—may be equated with close approximation to the three European stages, Lattorfian, Rupelian and Chattian respectively. The Padaung or Yenangyat-Minbu fauna and that of the Lower Nari in western India have a considerable proportion of species in common, in spite of the difference in facies shown by the two formations. The correlation of the latter is rendered more acceptable if the Ligurian fauna of north Italy, which is the close equivalent of the Lower Nari, is assigned to the Rupelian rather than to the Lattorfian.

THE LOWER PEGU.

The Shwezetaw stage.—The Shwezetaw Sandstone is one of the three principal coal-bearing formations of the Burma Tertiaries, the other two being the Yaw Shales and the Pondaung Sandstone.[26] In the type area of Ngape in south Minbu, where is to be seen the celebrated pagoda after which the stage is named, the Shwezetaw beds, massive sandstones alternating with shales, are nearly 3,000 feet thick; they show no angular discordance with the Eocene beds below,[27] from which, however they are separated by a thick bed of red earth. Nearly half-way up from the base occurs a fossil bed with the characteristic *Ampullina* (*Magatylotus*) *birmanica* Vred., a form close to *A. crassatina* Lam. found in the Oligocene of Europe and the Nari of Baluchistan. In the central parts of Thayetmyo it has been found difficult to draw a boundary between the Eocene and Pegu, in spite of the fact that the shales of the lower Pegu differ from those in the Eocene in appearance and in having no coal

[24] 'World Petroleum Congress' (Inst. Petrol. Tech.), 7-13 (1933).

[25] Journ. Inst. Petrol. Tech., Vol. 11, No. 50, p. 300 (1925).

[26] K. A. K. Hallowes, Rec. 51, 35 (1920).

[27] G. de P. Cotter, Rec. 41, 230 (1912); E. Vredenburg, Rec. 53, 363 (1921).

intercalations.[28] Here the boundaries of the Padaung Clay stage become obscure owing to the development of argillaceous beds in the Shwezetaw stage below as well as the overlying stage. In western Thayetmyo the Shwezetaw stage maintains its thickness and fossiliferous character, and consists of a massive sequence of fine-grained, rather shaly, micaceous sandstones, which form many of the ridges of this region[29]; here again the beds in places appear to have taken on the facies of the Padaungs and there is no well marked boundary between the Eocene and basal Pegu beds of Padaung aspect.[30] The Shwezetaw Sandstone is probably present among the lowest beds exposed in Myinmagyitaung and Thondaung in eastern Thayetmyo. Towards the northern part of Minbu, where the stage is made up of sandstones with coal seams and a few bands of limestone, the beds become practically barren of fossils. A few fossils have been found near Kyauk-o and specimens of *Heterostegina* in the Nhahlaingdwin anticline, where the thickness exposed is about 3,500 feet. The *Ampullina birmanica* bed is found in this anticline in its usual position. A synclinal basin mapped by Clegg in north Minbu, west of the Nwamataung strike fault, exposes the Shwezetaw Sandstones. West of Myaung-u the upper horizons of the Shwezetaw Sandstones include intercalations of shelly conglomerate;[31] lower in the sequence the sandstones themselves become calcareous but true sandstones and conglomerates do occur. In south Pakokku Cotter finds that the lithological planes of subdivision transgress over the faunal planes in the way already described (p. 1688), with the result that sandstones which correspond to the *Velates* bed found elsewhere at the top of the Yaws, now occur among the basal beds of what appears to be the Shwezetaw stage (*Velates* being absent from the Yaws of this area). In central Pakokku coal seams of poor quality are well developed in the country immediately south of the Yaw river,[32] while other local characteristics of the stage are the presence of gypsum and abundant fossil wood; here the boundary between the Shwezetaw stage and the underlying Eocene is somewhat ill-defined. In the country west of Myaing the Shwezetaws are probably represented by some coarse sandstone with fossil wood. In North Pakokku and the southern borders the Lower Chindwin district the predominant member of the stage, which here apparently covers a considerable area, is a pepper-and-salt sandstone, soft, friable and fine in grain; higher in the sequence bands of light blue clay or shale, some of them 20 feet in thickness, make their appearance, but are inconstant and pass laterally into sandstones. In places the Shwezetaws of this area are friable white sandstones scarcely distinguishable from those of the much younger Irrawadian. In the Kyaw valley, however, the Schwezetaw stage can be recognised by the

[28] Gen. Rep. Rec. 56, 40 (1924).
[29] Gen. Rep. Rec. 71, 57 (1936).
[30] Gen. Rep. Rec. 58, 45 (1925).
[31] E. L. G. Clegg, Mem. 72, 250 (1938).
[32] G. de P. Cotter, Rec. 44, 167-168 (1914); for analyses of the coal. See C. H. Lander, Rec. 56, 379 (1924).

occurrence in one or two localities of *Ampullina, Dolium, Conus, Plutotoma, Oliva, Natica, Trochus* and a *Voluta* comparable to *Athleta jacobsi* Vred. In the Shinmadaung area, 3,000 feet or more of the Shwezetaw Sandstone (Shinmadaung Sandstone) are exposed, the *Ampullina* bed occurring in its usual position; it includes an interbedded band of volcanic tuff. Faulted against newer beds along its western side, it forms hilly ground along two semilunar outcrops, of which the more northerly culminates in the conspicuous mass of Shinmadaung. In the Powin Taung and Ingyin Taung area the basal Pegu bed is a distinctive conglomerate, some four feet thick, consisting of rectangular and sub-rectangular fragments of shale in a matrix of soft buff sandstone.

The scanty fauna of the Shwezetaw stage comprises the following forms:—

ECHINOIDEA.

Eupatagus rostratus d'Arch.,
Clypeaster sp.

LAMELLIBRANCHIATA.

Ostraea sp.,
Cardita cf. *mutabilis,*
Cardita cf. *keyserlingi* d'Arch. & H.,
Venus aglaurae Brongn. ("*V. granosa*" of former writers),
Corbula subexarata d'Arch. (a Kirthar form),
Donax sp.,
Lucina sp.,
Tellina cf. *protocandida* Noetl.,

CASTROPODA.

Natica sp.,
Vermetus javanus Mart.,
Ampullina (*Megatylotus*) *birmanica* Vred.,
Vicarya cf. *verneuili* d'Arch.,
Turritella cf. *halaensis* Cossm.,
Turbo cf. *punjabensis* d'Arch. & H.,
Surcula cf. *voyseyi* d'Arch. & H. (a Ranikot species),
Trochus (*Tectus*) cf. *cognatus* Sow. (a Gaj species),
Strombus sp.,
Pyrula (*Ficula*) sp.,
Cassis sp.,
Purpura sp.

In central Pakokku occur the fresh or brackish water forms, *Cyrena borneensis* Bottg. and another species of the same genus.

The Padaung stage.—In the type area of Ngape in south Minbu the Padaung stage, 1,300 to 1,500 feet thick, forms an easily recognisable sequence consisting of blue grey clays with a subordinate 35-foot bed of grey earthy limestone towards their upper limit; this limestone, which dies out southwards, has yielded *Lepidocyclina elephantina* M.-Chalm. (Synonymous with *Orbitolites mantelli* Cart., var. *theobaldi* Cart.), *Heterostegina* sp. and *Pecten* cf. *subarcuatus* Tourn. From the shales or clays above the limestone come *Triconidea martiniana* (Noetl.), *Conus protofurvus* Noetl., *Turritella*

angulata Sow., *Solarium sp.* and *Cytherea* sp. In the shales or clays below the limestone have been found: *Schizaster* cf. *baluchistanensis* d'Arch., *Fasciolaria nodulosa* Sow., *Conus literatus* Linné, *Tritonidea martiniana* (Noetl.), *Tellina* sp. cf. *protocandida* Noetl., *T.* sp. cf. *hilli* Noetl., *Turritella angulata* Sow., *Strioterebrum* sp., *Pleurotoma* cf. *karenaica* Noetl., *Pyrula* (*Ficula*) sp., *Genota* sp. cf. *irravadica* Noetl., *Dione* sp. and crab claws.[33] The Padaung Clay has been recognised by Clegg in a synclinal basin east of the Ngape area and is here faulted against Pondaung sandstones. As a long narrow outcrop it stretches northwards to Kyaung-u, where it comprises a lower band of clay, 800 feet thick, an upper band of clay, 700 feet thick, and an intervening 330 feet of pepper-and-salt or reddish gritty sands with fossil bands.[34] In this outcrop of the Padaung beds occur *Lepidocyclina elephantina* Tourn., another species of this genus, and *Heterostegina* sp.[35] The Myaung-u locality has yielded *Melongena acanthina* (Dalt.), *Marginella orientalis* Vred. and *Athleta* (*Volutospina*) *jacobsi* Vred. A *Lepidocyclina* limestone similar to that mentioned above occurs in the Henzada district.[36]

The bulk of the Pegu rocks exposed in the Minbu anticline belongs to the Padaung (Minbu-Yenangyat) stage and includes Noetling's zone of "*Concellaria martiniana*". The following list is compiled from Noetling's list, partially corrected by Vredenburg, and from additional forms found by the writer in the lower horizons of the anticline:[37]

FORAMINIFERA.

Rotalia sp.,

ALCYONARIA.

Dendrophyllia macroriana Pasc. & Cott.

LAMELLIBRANCHIATA.

Ostraea sp. (a thick-shelled species),
Nucula alcocki Noetl. (N.),
Chlamys irravadicus Noetl. (N.),
Arca bistrigata Dunc. (N.),
Arca nannodes K. Mart.,
Cardita (*Venericardia*) *noetlingi* Cott.,
Meretrix (*Tivela*) *dubiosa* (Noetl.) (Noetling's "*Dione dubiosa*"), (N),
Meretrix (*Tivela*) *prootophilippinarum* (Noetl.) (Noetling's "*Dione protophilippinarum*"),
Tellina hilli Noetl. (N.),
Psammobia (*Gari*) *kingi* (Noetl.) (N.),
Corbula (*Bicorbula*) *prototruncata* Noetl. (N.),
Pholas sp.

[33] G. de P. Cotter, Rec. 41, 223 (1911).
[34] E. L. G. Clegg, Mem. 72, 248 (1938).
[35] Gen. Rep. Rec. 56, 39 (1924).
[36] G. de P. Cotter, Rec. 54, 111 (1922).
[37] (N)—determinations by Noetling unrevised. A revision of the lamellibranchs is especially desirable in view of the wider geographical distribution of that group of the mollusca as compared with the gastropods; Vredenburg's intended revision of this group was unfortunately, prevented by his death.

GASTROPODA.

Calliostoma blanfordi Noetl.,
Solarium (Architectonica) maximum Philippi (N.),
Torinia protodorsuosa Noetl. (N).
Torinia buddha Noetl. (N.),
Discohelix minuta Noetl. (N.),
Lacinia minbuensis Vred.,
Scalaria spathica Noetl. (N.).
Scalaria birmanica Noetl. (N.),
Scalaria irregularis Noetl. (N.),
Turritella magnasperula Sacco.,
Siliquaria sp.,
Sigaretus neritoideus Linne (N.),
Calyptraea rugosa Noetl. (N.),
Natica obscura Sow. (N.),
Ampullina (Cernina) callosa (Sow.) Noetling's "*Natica callosa*",
Cypraea (Cypraeotrivia) oppenheimi Vred.,
Cypraea (Bernayia) subexcisa Braun, var. *minbuensis* Vred.,
Cassis birmanica (Vred.) (Noetling's "*Cassis d'Archiaci*"),
Tritonium (Lampusia) dubium (Noetl.),
Cyrtochetus (Loxotaphrus) minbuensis (Noetl.) (extremely close to *C.* (*L.*) *phosvaricifer* Tate, from the Tertiary of Australia),
Pyrula concinna Beyr.,
Pyrula (Ficula) condita Brongn.? var. *singuensis* Vred.,
Hindsia neastriatula (Noetl.),
Hindsia pardalis (Noetl.),
Hindsia neacolubrinus (Noetl.),
Hindsia (Nassaria) birmanica Vred. (Noetling's "*Cancellaria davidsoni*"),
Ranella tubercularis Noetl.,
Clavilithes (Cyrtulus) seminudus (Noetl.),
Siphonalia (Kelletia) irravadica Vred.,
Murex (Chicoreus) arakanensis Noetl.,
Murex (Muricantha) irravadicus Vred.,
Volvaria birmanica Noetl.,
Voluta ringens Noetl. (N.),
Athleta (Volutospina) jacobsi Vred.,
Olivella minbuensis Vred.,
Olivancillaria (Agarona) nebulosa Lam.,
Lathyrus indicus Vred.,
Melongena (Pugilina) praeponderosa Vred.,
Tritonidea (Cantharus) martiniana (Noetl.).
Terebra (Subula) noetlingi vred.,
Surcula scala Vred.,
Surcula (Pleurofusia) feddeni Noetl.,
Genota irravadica Noetl.,
Drillia protointerrupta Noetl.,
Clavatula protonodifera Noetl.,
Conus (Lithoconus) ineditus Mich. (Noetling's "*Conus malaccanus*"),
Conus (Lithoconus) odengensis Mart., *var. avaensis* Nietl.

SCAPHOPODA.

Dentalium junghuhni K. Mart. (N.).

ARTHROPODA.

Balanus (Chirona) birmanica Withers.,[88]
Callianassa birmanica Noetl. (N.),
Cancer sp.

[88] Rec. 54, 288 (1922).

PISCES.

Myliobates sp.,
Sphyrna prisca Ag. (?),
Galeocerdo sp.,
Oxtrhina (Lamna) spalanzanii Bonap.,
Fish otoliths.

The Padaung stage has been recognised in the Thondaung and Myinmagyi-taung area of Thayetmyo, and also at Letpanzeik, five miles north of Thayetmyo town; in both these areas there occurs a *Lepidocyclina* limestone with *Lepidocyclina elephantina* M.-Chalm. In the Kyawdo-Sanaing and Yein-Tamagyaw anticlines the Padaung stage and perhaps lower horizons are exposed, the beds being chiefly argillaceous limestone or indurated calcareous shale with subordinate bands of sandstone.[39]

The Padaungs form a constant belt from the Ngape area northwards to the southern borders of Pakokku, beyond which they cannot be individually recognised since they pass laterally into sandstones which form part of a thick indivisible sequence of coastal or fresh-water Pegu beds to be referred to later on. This lateral change takes place at approximately the same latitude which witnesses the replacement of the *Velates* bed at the top of the Yaws by sandstones at the base of the Shwezetaws. Traces of the Padaung fauna, however, have been found in the more central parts of Pakokku, where *Meretrix (Tivela) protophilippinarum* (Noetl.), *Calliostoma* sp., a coral resembling *Dendrophyllia digitalis* Blainv., and a doubtful cast of *Tritonidea martiniana* have been collected. The Padaung stage is definitely recognisable in the Yenangyat anticline, in the south-east corner of the district; here it includes Noetling's two zones "*Dione dubiosa*" and "*Paracyathus coeruleus*" the combined faun of which is as follows:[40]

ACTINOZOA.

k. *Paracyathus* sp. cf. *tasmanicus* or *supracostatus* (both Australian species),
s. *Eupsammia (Balanophyllia)* sp.

LAMELLIBRANCHIATA.

s. *Chlamys irravadicus* Noetl.,
s. *Arca bistrigata* Dung.,
s. *Nucula alcocki* Noetl.,
k. *Lucina pagana* Noetl.,
Lucina d'Archiaciana Noetl.,
s. *Meretrix (Pitar) amygdaloides* (Noetl.),
Meretrix (Tivela) dubioso Noetl. (Noetling's "*Dione dubiosa*").
k. *Meretrix (Tivela) protophilippinarum* Noetl.,
Tellina hilli Noetl.,
k. *Gari kingi* Noetl.,
s. *Corbula (Bicorbula) prototruncata* Noetl.

GASTROPODA.

s. *Architectonica maxima* Philippi,
Calliostoma blanfordi Noetl.,

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[39] Gen. Rep. Rec. 47, 32 (1916).
[40] G. de P. Cotter, Mem. 72, 94-96 (1938).

Torinia buddha Noetl.,
Scalaria (*Clathrus*) *leptopleuratus* Noetl. (Noetling's *Scalaria leptopleurata*),
k. *Ampullina* (*Cernina*) *callosa* (Sow.),
k. *Natica obscura* Sow.,
k. *Sigaretus neritoides* Linne,
s. *Turritella magnsperula* Sacco,
s. *Calyptraea rugosa* Noetl.,
s. *Pyrula* (*Ficula*) *condita* Brongn.,
s. *Cypraea* (*Cypraeotrivia*) *oppenheimi* Vred.,
Trivia noetlingi Verd.,
Hindsia neastriatula (Noetl.),
Hindsia birmanica Vred.,
k. *Hindsia pardalis* (Noetl.),
Ranella tubercularis (Noetl.),
k. *Clavilithes seminudus* (Noetl.),
Lathyru sindicus Vred.,
s. *Tritonidea martiniana* (Noetl.), (N.),
Murex (*Muricantha*) *irravadicus* Vred.,
Murex (*Muricantha*) *irravadicus* var. *yenanensis* Vred..
s. *Athleta* (*Volutospina*) *jacobsi* Vred.,
s. *Melongena acanthina* (Dalt.),
s. *Athleta* (*Volutospina*) *jacobsi* Vred., var. *singuensis* Vred.,
Olivella minbuensis Vred.,
Morica pseudocanellata (Noetl.),
Fasciolaria feddeni (Noetl.),
Surcula (*Pleurofusia*) *feddeni* Noetl.,
Drillia interrupta Noetl.,
s. *Terebra quettensis* Vred.,
Pleurotoma (*Hemipleurotoma*) *yenanensis* Noetl.,
s. *Conus* (*Lithoconus*) *ineditus* Mich.,
Conus (*Leptoconus*) *protofurvus* Noetl.,
Conus (*Conospira*) *galensis* Noetl.

ARTHROPODA.
k. *Balanus* (*Chirona*) *birmanicus* Withers.

PISCES.
Oxyrhina (*Lamna*) *spalanzanii* Bonap.

s. also in the superjacent Singu Stage,
k. also in the Kama stage.

Of the 48 species and varieties, 19 occur neither in the Singu nor the Kama stages, while only 10 range as far as the Kama. The correlation of these Yanangyat beds is based not only upon the similarity of fauna but also upon stratigraphical position beneath the Singu stage. Of secure determinations, less than 6 per cent. of the Yenangyat-Minbu fauna are living forms. The fauna of the main Yenangyat fossil bed may perhaps represent a slightly older horizon of the Padaung stage than the main fossil bed found in the Minbu anticline which may occupy a more central position in the Padaung stage.[41] This would place the Minbu fauna between the Yenangyat and Singu faunas. The Padaung stage maintains its marine character into the northern or Sabe end of the Yenangyat fold, in contrast to the overlying Singu and Kama stages which assume an estuarine

[41] E. Vredenburg, Rec. 51, 232 (1920).

or fresh-water facies; at this end of the anticline the Padaungs form a succession of well bedded sandstones and shales with bands of limestone and marl and well preserved fossils.[42]

From an old hand-dug oil well at Yenangyat, Noetling obtained a small specimen of the fossil resin, *Burmite,* which occurred in beds containing the usual Pegu fossils.[43]

In the Gwegyo inlier of Myingyan we find the usual change to shallower water sediments from south to north, a change which continues in the Pagan inlier further north. From the extreme northern end of the Gwegyo outcrop a few Padaung fossils have been identified by Vredenburg:[44]

GASTROPODA.

Surcula birmanica Vred.,
Ancilla (Sparella) indica Vred., var *arakanensis* Vred.,
Athleta (Volutospina) jacobsi Vred.,
Fusus buddhaicus Vred.,
Lathyrus sindiensis Vred., var. *birmanica* Vred.,
Lathyrus indicus Vred.,
Melongena (Pugilina) praeponderosa Vred.

From two or three separate horizons in the Payagyigon or southern end of the anticline Cotter has collected a much richer fauna,[45] which it is not necessary to detail in full; among the specimens are:[46]

LAMELLIBRANCHIATA.

Tellina indifferens Noetl.,

GASTROPODA.

Scalaria sp.,
Mitra sp.,
Rimella (Dientomochilus) promensis Vred.,
Hindsia birmanica Vred.,
Olivella minbuense Vred.,
Cypraea (Cypraeotrivia) oppenheimi Vred.,
Pleurotoma (Hemipleurotoma) yenanensis (Noetl.),
Pleurotoma (Hemipleurotoma) humilis Beyr., var. *irrvavadica* Vred. (species in the Oligocene of Europe),
Pleurotoma cf. *woodwardi* Mart.,
Pleurotoma cf. *tigrina* Mart.,
Drillia protointerrupta Noetl.,
Surcula (Pleurofusia) feddeni Noetl.,
Surcula (Pleurofusia) fusus Vred.,

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[42] G. de P. Cotter, Mem. 72, 92 (1938).
[43] Rec. 26, 40 (1898).
[44] G. de P. Cotter, Mem. 72, 98 (1938).
[45] Rec. 37, 230 (1908).
[46] Mem. 72, 99 (1938; Rec. 36, 131 (1907).
From unstated localities and horizons in the Payagyigon-Ngashandaung area the following additional species were recorded: *Ceratotrochus alcockianus* Noetl., *Temnopleurus* sp., *Tellina grimesi* Noetl., *Pyrula Condita* Brongn. *Calliestoma* sp., *Siliquaria* sp., *Basilissa lorioliana* Noetl., *Nautilus* sp., and *Balanus (Chirona) birmanicus* With. The fossils from the Payagyigon-Ngashandaung area have been subjected to considerable pressure. *Carcharodon angustidens* Agass. is recorded from the Pegus of the Pagan Hills.

Conus (*Lithoconus*) *ineditus* Mich.,
Athleta (*Volutospina*) *jacobsi* Vred.,
Turricula birmanica Vred.,
Fusus humei Vred.,
Lyria varicosa Vred.,
Euthriofusus alomprae Vred.,
Lathyrus sindiensis Vred., var. *birmanica* Vred.,
Lathyrus indicus Vred.,
Siphonalia cotteri Vred.,
Cyrtochetus (*Lootaphrus*) *minbuensis* (Noetl.),
Tritonidea martiniana (Noetl.), var. *arakanensis* Vred.

From the Padaungs south of Ngahlaindwin come: *Clavilithes seminudus* (Noetl.), *Terebra* (*Myurella*) *quettensis* Vred., *Marginella orientalis* Vred., *Athleta jacobsi* Vred., *Surcula* (*Pleurofusia*) *feddeni* Noetl., and *Melongena acanthina* (Dalt.) In the Ngahlaingdwin anticline itself the stage is from 1,000 to 1,500 feet thick and has yielded:

LAMELLIBRANCHIATA.

Nucula alcocki Noetl.,
Tellina protocandida Noetl.,
Tellina indifferens Noetl.,
Meretrix (*Tivela*) *protophillipinarum* (Noetl.).

GASTROPODA.

Genota irravadica Noetl.,
Cypraea (*Bernayia*) *subexcisa* Braun.,
Clavilithes seminudus (Noetl.),
Clavilithes arakanensis Vred.,
Hindsia pardalis (Noetl.),
Sigaretus neritoides Linn., sec. Noetl.,
Athleta (*Neoathleta*) *theobaldi* Vred.,
Lyria varicosa Vred.,
Melongena praeparadisiaca Vred.,
Tritonidea martiniana, var. *arakanensis* Vred.

In the Salin section of north Minbu the Padaungs have been divided into three zones as follows:

Upper, rich in *Tritonidea martiniana, Melongena praeperadisiaca,* and *Tellina* sp.;

Middle, with *Flabellum* and *Dendrophyllium;*

Lower, with *Ostraea.*

On the Pakokku-Minbu border the Padaung Clay is still a well marked band, varying from 1,000 to 1,500 feet thick, with abundant fossils among which are: *Tellina protocandida, Hindsia pardalis, Nautilus* sp. and *Lucina globulosa.*

In the Shinmadaung area of Pakokku the Shwezetaw Sandstone is overlain by 2,000 feet of the Padaung beds with *Melongena praemelongena* Vred.,[47] and *Tritonidea martiniana* (Noetl.), the lower 800 or 1,000 feet of which consist almost entirely of shale, the rest of the stage comprising shale with numerous intercalations of thin sandstone. ....

[47] Rec. 55, 63 (1923).

The Padaung Clay forms part of the sequence of eastern Thayetmyo, in the neighbourhood of the hills, Myinmagyitaung and Thondaung, and includes a limestone band with "*Lepidocyclina theobaldi*", a foraminifer now equated with *L. elephantina* M.-Chalm. From the upper part of the Sitsayans in the northern part of the district come the following (Mindegyi locality):

ECHINOIDEA.
Breynia birmanica Vred.,
Brissopsis fermori Vred.,[48]
Thylechinus sethuramae Vred.

LAMELLIBRANCHIATA.
Placuna (Indoplacuna) birmanica Vred.

GASTROPODA.
Melongena (Pugilina) ickei Mart.,
Siphonalia (Kelletia) irravadica Vred.,[49]
Tritonidea martiniana (Noetl.),
Olivella minbuensis Vred.,[50]
Terebra (Duplicaria) cotteri Vred. (very close to the living *T. duplicata* (*Linne*),
Terebra (Duplicaria) woodwardiana Mart., var. *mindegyiensis* Vred. (Species from Java),
Ancilla (Sparellina) poenitens Vred.,
Athleta (Volutospina) jacobsi Vred., *and* variety, *singuensis* Vred.,
Cypraea (Bernayia) subexcisa Braun, var. *ngahlaingdwinensis* Vred.,
Surcula (Pleurofusia) feddeni Noetl.,
Pleurotoma (Hemipleurotoma) yenanensis (Noetl.),
Clavatula protonodifera Noetl.,
Drillia (Brachytoma) pinfoldi Vred.

The Sitsayan Shales of Prome and Henzada.—Western Prome is the type area of the Sitsayan (Sitsyahn) Shales which, from considerations of general facies and stratigraphical position, are in all probability the equivalent of the Padaung Clays but which may, in the original use of the term, include horizons lower than the Padaungs and belonging to the Shwezetaw stage. Exposed on the western bank of the Irrawaddy, where they cover a considerable area, the Sitsayan Shales consist for the most part of soft, unfossiliferous, blue, clunchy clay with very little appearance of bedding except towards its upper portion where in the Henzada district a band of limestone is developed. It is said to bear a strong resemblance to some of the Eocene shales but is paler in colour , when dried it cracks and falls to pieces spontaneously.[51] Occasionally the monotony is relieved by occasional irregular layers of yellow, pale blue or grey marl, some of it fibrous and most of it traversed by septarian cracks filled with calcite ; cone-in-cone structure is sometimes seen. The limestone band, in Henzada composed of a white, sometimes pink, limestone, crowded with small lepidocyclines, small nummulites and occasional fragments of *Cycloclypeus,* is usually massive but in some

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[48] Rec. 54, 413-414 (1922).
[49] Rec. 55, 67 (1923).
[50] Rec. 54, 250 (1922).
[51] W. Theobald, Mem. 10, 270 (1873).

places is made up of a series of thin flaggy limestones with shaly partings. The hill in Henzada, Tondaung, is formed of the massive variety of this limestone. At Sitsayan itself Vredenburg obtained unidentifiable specimens of fish teeth and scales, and shells including *Capulus, Corbula* and *Pecten.*[52] The Sitsayan Shales rest upon the Eocene where unfaulted junctions occur and a considerable unconformity occurs between the two formations. The Sitsayan Shales contain near their base occasional worn fragments of the Eocene sandstones and limestones and, when traced from north to south by Stuart, were found to overlap bed after bed of the older series.[53] The sandstones underlying them in the Henzada district are not the Shwezetaw sandstones but probably occupy a place in the Eocene lower in the scale than those found in a similar position in the Prome district.[54] The thickness of the Sitsayans was originally given as 800 feet, but an accurate estimate was impossible. In the Henzada district the beds form part of the interrupted Tertiary fringe to the tract of Negrais rocks, from which they are separated by an extensive fault. At Kywezin, some 32 miles northwest of Henzada town, a compact, white limestone, belonging to this stage, has yielded lepidocyclines and nummulites which have not yet been determined.[55]

Evidence of the regression of the sea from north to south is well seen in the latitudinal variation of the Padaung or Sitsayan stage. In the Ngape section of south Minbu are deep-water clays with limestone; in north Minbu there is no intercalated limestone, but the clays are still well developed; across the Saw-Seikpyu road in south Pakokku the clays grade into sands; while finally, in the Yaw river section of north Pakokku, there are nothing more than current-bedded sandstones throughout the stage.[56]

The Singu stage.—The Singu stage is most typically developed in the Singu oilfield (see p. 1692). In the Ngahlaingdwin area of north Minbu it is about 5,000 feet thick and consists of alternate sandstones and shales with occasional bands of clay ironstone and conglomerate. Near the top occurs *Turritella angulata* Sow., a common Gaj form whose specific distinctness from the living *T. duplicata* is not quite certain; near the base are found:

LAMELLIBRANCHIATA.

Nucula alcocki Noetl. (N.),
Tellina protocandida Noetl. (N.)
Cardita (*Venericardia*) *noetlingi* Cott. (erroneously attributed by Noetling to *C. visquesneli* d'Arch. & H.),
Meretrix (*Tivela*) *protophillipinarum* Noetl.

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[52] Rec. 51, 231 (1920).
[53] Rec. 38, 262 (1909).
[54] M. Stuart, Rec. 41, 249 (1911).
[55] E. Vredenburg, Rec. 34, 93 (1906)
[56] G. de P. Cotter, Rec. 44, 166 (1914).

GASTROPODA.

Hindsia birmanica Vred.,
Sigaretus neritoides Linn., sec. Noetl.,
Athleta jacobsi Vred.,
Olivella minbuensis Vred.

In is probable that the uppermost Pegu beds of the Minbu anticline belong to the Singu stage. Overlying the Padaung (Minbu) stage, they include a fossil band characterised by the abundance of an Arca identical with the living *Arca rhombea* Born.; in addition are found:

ACTINOZOA.
Dendrophyllia sp.

LAMELLIBRANCHIATA.
Ostraea sp.,
Meretrix (*Tivela*) *pritophilippinarum* (Noetl.),
Corbula sp.,
Telescopium subtrochleare d'Arch. & H.[57] (found also in the Eocene of Sind).

GASTROPODA.
Natica gracilior Noetl. (N.).

FISH OTOLITHS.
Python molurus Linné.

From a high horizon in the Pegu of Minbu, which may or may not be the same as that of the *Arca* bed, comes also *Athleta* (*Neoathleta*) *theobaldi* Vred.

Along both banks of the Irrawaddy from Thayetmyo town northwards, the lowest beds locally exposed in anticlinal structures probably belong to the Singu stage and include the *Dendrophyllia* bed with species of *Dendrophyllia, Schizaster* and *Nucula, Terebra* (*Myurella*) *quettensis* Vred., (a characteristic fossil of the Baluchistan Nari) *Surcula fusus* Vred., *Conus ickei* Mart. (the "*Conus literatus*" of Noetling), and *Tritonidea martiniana* (Noetl.); at least 2,500 feet of these beds are seen underlying the Kama Clay. Along the Okhminataung ridge, N. N. W. of Thayetmyo, the Singu stage is represented by sandstones, well seen at Kyaukme and Monatkon.[58]

The Pegus exposed at Migyaungwe in the Magwe district belong in all probability to the Singu stage and have yielded *Cancellaria birmanica* Vred.

Immediately north of Ngahlaingdwin the Singu stage is still recognisable, but further north the shales so abundant in the south rapidly give place to sandstones or quartz-pebble conglomerates with much silicified wood, and Bion has found it impossible to trace the stage amongst the rest of the Pegu beds, the general decrease in thickness adding to the difficulty; in the country immediately north of Ngahlaingdwin the total thickness from the base of the Singu

[57] E. L. G. Clegg, Mem. 72, 269 (1938).

[58] E. L. G. Clegg, Mem. 72, 247 (1938).

stage to the top of the Pegu series is 1,200 feet, while in the Kyaw area of north Pakokku it is only 700 feet.

The Lower Prome stage.—In the Prome district the equivalent of the Singu stage is known as the Lower Prome beds which, according to Theobald, are distinguishable in the field from the Upper Prome beds, the equivalent of the Kama stage,[59] by the different topography to which they give rise, the outcrops of the Upper Prome beds being softer and occupying lower hills than do those of the Lower Prome. Both Lower and Upper divisions of the Prome are exposed on both sides of the river Irrawaddy, the former lying conformably upon the Sitsayan Shales and the latter overlain by the Pyalo beds where the contacts are normal; on the western bank the Prome beds, bent into anticlines and synclines, have been affected by a large oblique fault. The beds comprise sandstones and shales, the former grey or yellow in colour, sometimes hard, but more frequently argillaceous or shaly. The shales or clays vary in colour, blue being a common shade. Marly concretions are seen in some of the alternations of sandstone and shale. There is a predominance of sandstone over shale in the Lower Prome and the contrary in the Upper division. Where fully developed, just north of the town of Prome, the total thickness of the Prome stage has been estimated by Murray Stuart to be 2,200 feet;[60] of this about three-quarters belong to the Lower division, but a total of 2,500 feet is quoted in the last edition of this Manual with reference to sections opposite Prome.

The Lower Prome (Theobald's "Division A"), though containing no distinctive fossil horizons, is not devoid of organic remains, as was assumed by Noetling. In some massive sandstones at the base Stuart has found abundant echinoderms, each wrapped in a ferruginous concretion, sharks teeth including *Carcharias* (*Aprionodon*) sp., *C.* (*Prionodon*) sp. and *Galeocerdo latidens* Agass. (a Mozambique form), and the cephalothorax of an indeterminate, brachyurous crab, while a bed near the top is full of *Turritella angulata* Sow. (the *T. simplex* Jenk, and *T. acuticarinata* Dunk. of Noetling). Generally speaking, however, the Lower Prome contains few fossils.

In the Henzada district the Akauktaungs together with some doubtful underlying beds which may represent the Pyalo stage, are superposed on the Sitsayan Shales, and the Prome and Kama stages are missing.[61]

The Singu stage.—Beneath the Kama stage in the type area of the Singu oilfield are exposed about 1,500 feet of highly fossiliferous beds consisting of the usual alternations of well bedded sandstone and blue shale with bands of marl or limestone. This Singu stage, therefore, is of about the same thickness as its equivalent, the Lower Prome (Prome "A"). In it some ten fossil bands have been traced by

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[59] E. Vredenburg, Rec. 51, 231 (1920).
[60] Rec. 38, 261 (1909).
[61] Rec. 41, 244-250 (1911).

S. R. Rau, and have yielded a combined fauna which in character is nearest the Chattian of Europe, and possesses over 10 per cent. of living species of gastropods. Faunistically it occupies an intermediate position between the Lower Nari and the Gaj and approximates, therefore, to the Upper Nari. Summarised by Cotter[62] and including many of Noetling's unrevised determinations, especially the lamellibranchs, it comprises the following:

ECHINOIDEA.

Thylechinus sethuramae Vred., (genus found in the Nari of Baluchistan).

ANTHOZOA.

Dendrophyllia digitalis Blainv.,
Dendrophyllia macroriana Pasc. & Cott.,
p.k. *Paracyathus* sp. cf. tasmanicus.,
p. *Eupsammia* sp.

LAMELLIBRANCHIATA.

Lima protosquamosa Noetl. (N.),
p. *Chlamys irravadicus* (Noetl., (N.),
Pteria suessiana Noetl., (N.),
k. *Vulsella lingua-tigris* Noetl. (N.),
Mytilus (Septifer) nicobaricus Reeve (N.),
Modiola buddhaica Noetl. (N.),
Lithophaga sp.,
p. *Arca bistrigata* Dunc., (N.),
p.k. *Nucula alcocki* Noetl. (N),
Nuculana (?) *birmanica* Noetl. (N.),
Cardita scabrosa Noetl. (N.),
Cardita (Arcinella) tjidamarensis Mart., (N.),
k. *Venericardia noetlingi* Cott., (Noetling's *Cardita viquesneli*),
Crassatella dieneri Noetl., (N.),
k. *Cardium (Trachycardium) minbuense* Noetl., (N.),
Meiocardia metavulgaris Noetl., (N.),
Venus (Antigona) granosa (Sow.) (N.),
k. *Meretrix (Dione ; Pitar) protolilacina* Noetl. (N.),
p.k. *Meretrix (Dione ; Pitar) amygdaloides* Noetl. (N.),
p.k. *Meretrix (Tivela) protophilippinarum* (Noetl.), (N.),
k. *Tellina (Apolymetis) grimesi* (Noetl.), (N.),
p. *Gari kingi* Noetl., (N.),
Gari deuterokingi Noetl.,
Corbula rugosa Sow., (N.),

SCAPHOPODA.

k. *Dentalium junghuhni* Mart., (N.).

GASTROPODA.

p.k. *Solarium (Architectonica) maxima* Philippi (N.),
Calliostoma singuense Vred.,
K *Basilissa lioriolana* Noetl. (N.),
k. *Turcica protomonilifera* Noetl., (N.),
p. *Calyptraea rugosa* Noetl., (N.),
p.k. *Natica obscura* Sow., (N.),
p.k. *Sigaretus neritoides* Linne, (N.),
k. *Turritella anglulata* Sow. (found also in the Gaj of western India),
p. *Turritella magnsperula* Sacco (found also in the Oligocene of Europe),

[62] With a few unimportant modifications (Mem. 72, 88-90 (1938)).

Vicarya verneuili d'Arch. (found also in the Gaj),
p. *Cassis birmanica* Vred.,
k. *Cassidaria* (*Galeodea*) *echinophora* Linne, var. *monilifera* (Noetl.) (species living),
p. *Pyrula* (*Ficula*) *condita* Brongn., var. *singuensis* Vred. (species found in Piedmont, and in the Oligocene of Sind and Baluchistan),
Cypraea (*Cypraeotrivia*) *oppenheimi* Vred.,
Cypraea (*Bernayia*) *subexcisa* Braun.,
Pleurotoma (*Hemipleurotoma*) *singuensis* Vred. (close to *Pl. roemeri* von K. from the Oligocene of Helmstadt),[63]
Cypraea (*Bernayia*)*singuensis* Vred. (very close to *C. humerosa* Sow., a typical Gaj form),
k. *Persona* (*Distorsio*) *reticulata* Linné var, *subclathrata* d'Orb. (species) living),
p. *Tritonidea martiniana* (Noetl.),
Purpura (*Thais*) *singuensis* Vred.,
p.k. *Clavilithes seminudus* Noetl.,
Vasum basilicum Bellardi (found also in the Oligocene of Europe),
Melongena (*Pugilina*) *praeponderosa* Vred.,
Melongena pseudobucephala (Noetl.),
Melongena acanthina (Dalt.),
p. *Athleta* (*Volutospina*) *jacobsi* Vred., var. *singuensis* Vred.,
Lacinia minbuensis Vred. (An American Eocene genus, found also in the Yaw stage of Burma),
Mitra singuensis Vred. (related to *M. mettei* Gieb. from the Lower Oligocene of Latdorf),
Marginella singuensis Vred. (resembling *M. brevispira* Bell. from the Miocene of Turin),
p.k. *Olivancillaria* (*Agarona*) *nebulosa* Lam., var. *pupa* Sow. (found in the Gaj ; species living),
Ancilla (*Sparella*) *birmanica* Vred.,
Clavatula (*Perrona*) *birmanica* Vred., var. *singuensis* Vred.,
p. *Clavatula protonodifera* Noetl.,
p. *Genotia irravadica* Noetl.,
Genotia singuensis Vred.,
Conusickei Mart.[64]
p.k. *Conus* (*Lithoconus*) *odengensia* Mart., var. *avaensis Noetl.* (species found in the Gaj of India and the Miocene of Java),
p. *Conus* (*Lithoconus*) *ineditus* Mich. (Noetling's "*Conus malaccanus*"; found in the Nari of India),
p. *Terebra* (*Myurella*) *quettensis* Vred. (found also in the Nari),
p. *Surcula* (*Pleurofusia*) *feddeni* Noetl.

ARTHROPODA.

p.k. *Balanus* (*Chirona*) *birmanicus*,
p.k. *Calianassa birmanica* Noetl.,
p, found also in the underlying Padaung (Minbu Yenangyat stage),
k. found also in the overlying Kama stage.

PISCES.

Carcharodon lanceolatus Ag.,
Carcharias (*Aprionodon*) *frequens* Dames,
Carcharias (*Prionodon*) *egertoni* Ag..
Carcharias (*Prionodon*) *collata* (ex Cope),
Hemipristis simplex Stuart,
Hemipristis serra Ag.

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[63] Rec. 53, 98 (1921).

[64] E. Vredenburg, Rec. 51, 247 (1920).

As already mentioned the Singu anticline crosses the Irrawaddy and continues northwards in the Pakokku district where it is generally known as the Yenangyat fold. Three of the ten fossil beds found in the Singu stage of the Singu anticline, including the lowest, (the "*Dendrophyllia bed*") have been recognised in the southern portions of the Yenangyat fold. Traced northwards the facies of the Singu stage becomes more and more estuarine in character, the bands of fossiliferous marl and limestone becoming untraceable and replaced by shale and sandstone. At Sabe near the northern end of the Pegu outcrop, 1,600 feet of the Singu stage are exposed in the form of current-bedded sandstones, pale silty shales, some red earth and fossil wood, and a few bands of badly preserved fossils among which occur *Balanus birmanicus*, a large *Ostraea*, and crocodile bones.[65] From the behaviour of the fossil bands, there is reason to believe that the change in facies from Singu to Yenangyat is accompanied by a diminution in thickness.

An example of the rapidity with which lateral changes took place in the Burma Tertiaries is seen in the fact that, thirteen miles north-east of the northern termination of the Yenangyat inlier, Pegu rocks, if represented at all in the Myaing anticline, are reduced to 1,000 feet of fluviatile beds intervening between the Yaw stage of the Eocene and what appears to be definitely recognisable Irrawadian sandstone.

The higher beds exposed in the Gwegyo anticline have yielded a few fossils which may indicate the presence of the Singu stage; these are: *Tellina hilli* Noetl., *Arca submultiformis* Vred., *Meretrix (Tivela) protophilippinarum* (Noetl.), *Turritella angulata* Sow., *Hindsia pardalis* (Noetl.), *H. birmanica* Vred. This stage may also be present in the Pagan hills further north, but so far no fossils seem to have been collected from the supposed Singu horizons of this area.

From the Pegu beds of the Kabat anticline in Myingyan come *Conus (Lithoconus) ineditus* Mich., *C. (L.) ickei* Mart., *Melongena pseudobucephala* (Noetl.), and *Athleta (Volutospina) jacobsi* Vred., indicating the Singu stage.[66]

The Upper Pegu.—The Upper of Miocene portion of the Pegu series is equivalent to the succession in western India embracing the whole of the Gaj, some estuarine passage beds which follow and most of the Lower Manchhar. In northwest India the basal Aquitanian stage of the Upper Pegu is unrepresented but the rest of the division is present in the form of the Murree series and the Lower Siwaliks (Kamlial and Chinji stages). Although one of its stages has provided a rich fauna in one of its more southerly occurrences, the Miocene in Burma is generally speaking poorly developed and in most sections fossils are badly preserved or absent. Compared with the Oligocene portion of the Pegu, a larger proportion of the Miocene

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[65] G. de. P. Cotter, Mem. 72, 92 (1938).

[66] G. de. P. Cotter, Rec. 36, 132 (1907); E. Vredenburg, Rec. 51, 285-287 (1920).

consists of fresh-water or very shallow-water deposits, and this is increasingly so as one passes northwards. In north Minbu some 5,500 feet of the Upper Pegu are exposed, but in the Ngape area of south Minbu the total thickness is nearer 8,000 feet.[67]

The Kama stage.—The term, Kama Clay, was applied by Theobald to some fossiliferous blue shales and sandstones cropping out on the right bank of the Irrawaddy in the vicinity of the town of Kama, some eighteen miles above Prome. Fossils obtained from the type locality, which lies in the southern part of Thayetmyo, are, however, neither so numerous nor so well preserved as they are in exposures further north on the other side of the river in the same district. Here the beds cannot be less than 2,500 feet thick, the main fossil horizon occurring some 1,200 feet below the uppermost local limit of the Pegu. From several localities to the northeast of Thayetmyo town, the most important of which are Tittabwe, Thanga, Myaukmigon, Myauktin and Dalabe, (Kyaungon, Kyudawon, Myingabaing), S. R. Rau has collected a large number of specimens, some of them so well preserved as to show traces of original colour; they are characterised generally by the smallness of the species. The examination of this fauna has not yet been completed, but, as an example of its richness, no less than 155 species of siphonostomatous gastropods have already been determined. Of the gastropods specifically identified so far, nearly 7 per cent, 11 out of 156 are living forms, and the stage is thought to represent a portion of the Lower Gaj, the Rembang (Ramban) series of Java, and the Aquitanian of Europe. The following come from the Thayetmyo district; many of them are Noetling's determinations.[68]

ECHINOIDEA.

Cidarie sp.,

ACTINOZOA.

Ceratotrochus alcockianus **Noetl., (N.),**
Flabellum distinctum M.-Edw., (N.).

LAMELLIBRANCHIATA.[69]

Ostraea papyracea **Noetl., (N.),**
Chlamys articulatus Sow. (*Noetling's "Pecten kokenianus"*),
Vulsella lingua-tigris **Noetl., (N.),**
Arca (Anomalocardia) theobaldi **Noetl., (N.),**
Arca (Anomalocardia) myoënsis **Noetl., (N.),**
Arca (Anomalocardia) yawensis Noetl., (N.),
Arca (Barbatia) bataviana K. Mart., (N.).
Arca (Anadara) craticulata (Nyst.) (*Noetling's "Arca burnesi* d'Arch. & H."),
Arca (Scapharca) peethensis **d'Arch. & H. (N.),**
Arca metabistrigata **Noetl. (N.),**

[67] G. de. P. Cotter, Rec. 41, 229 (1911).

[68] E. Vredenburg, Rec. 53, 83-129, 130-141 (1921), Rec. 54, 243-275 (1922); E. Vredenburg, Mem. 50 (1925-1928).

[69] Noetling's two zones of "*Parallelipipedum prototortuosum*" and "*Arca theobaldi*" have been combined in this list, in deference to Vredenburg's opinion (Rec. 51, 245 (1920), though Noetling's two lists show considerable differences (Pal. Ind., New Ser., Vol. I, No. 3, pp. 23-25 (1901)).

Arca nannodes K. Mart. (N),
Parallelipipedum prototortuosum Noetl., (N.),
Nucula alcocki Noetl. (N.),
Nucula phayreiana Noetl. (N.),
Leda virgo Noetl. (N.),
Leda avaënsis Noetl. (N.),
Cardita protovariegata Noetl. (N.),
Cardita (Venericardia) noetlingi Cott.,
Lucina neasquamosa Noetl. (N.),
Lucina pagana Noetl. (N.),
Cardium protosubrugosum Noetl. (N.),
Cardium minbuense Noetl. (N.),
Meiocardia protovulgaris Noetl. (N.),
Meretrix (Cytherea) promensis Theob.,
Meretrix (Dione; Pitar) protolilacina Noetl. (N.),
Meretrix (Dione; Pitar) arakanensis Noetl. (N.),
Meretrix (Dione; Pitar)amygdaloides Noetl. (N.),
Meretrix (Tivela) protophilippinarum (Noetl.), (N.),
Dosinia protojuvenilis Noetl. (N.),
Placuna (Indoplacuna) promensis Vred.,
Tellina grimesi Noetl. (N.),
Tellina protostriatula Noetl. (N.),
Tellina protocandida Noetl. (N.),
Tellina indifferens Noetl. (N.),
Tellina foliacea Reeve (N.),
Tellina hilli Noetl. (N.),
Tellina pseudohilli Noetl. (N.),
Psammobia (Gari) natensis Noetl. (N.),
Psammobia (Gari) protokingi Noetl. (N.),
Hiatula textilis Noetl. (N.),
Mactra protoreevesi Noetl. (N.),
Corbula socialis K. Mart. (N.).

SCAPHOPODA.

Bicorbula prototruncata Noetl. (N.),
Dentalium junghuhni K. Mart. (N.),
Dentalium boettgeri Noetl. (N.).

GASTROPODA.

Calliostoma koenenianum Noetl. (N.),
Basilissa lorioliana Noetl. (N.),
Turcica protomonilifera Noetl. (N.),
Solarium (Architectonica) maximum Philippi (N.),
Scalaria birmanica Noetl. (N.),
Torinia protodorsuosa Noetl. (N.),
Calliostoma promense Vred. (restricted to the Kama stage).[70]
Calyptraea rugosa Noetl. (N.),
Terebra dalabeensis Vred. (Except for its much smaller size, the equivalent of *T. junghuhni* Mart. from Java),
Terebra (Duplicaria) theobaldi Vred. (Close to *T. gedrosiana* Vred. from the Mekran of Baluchistan),
Terebra (Duplicaria) protoduplicata Noetl.,
Terebra (Duplicaria) smithi Mart.,
Terebra (Subula) cossmanni Vred.,
Terebra (Subula) fuscata (Brocchi) (found also in the Miocene and Pliocene of Europe),
Terebra (Duplicaria) noetlingi Verd.,

[70] Rec. 51, 329 (1920).

Terebra (Myurella) promensis Vred.,
Terebra (Myurella) birmanica Vred.,
Terebra (Myurella) kyudawonensis Vred.,
Terebra (Myurella) martini Vred. (=*T. bicinta* Mart. from Java),
Terebra (Myurella) hornelli Vred.,
Terebra (Myurella) tipperi Vred.,
Terebra (Myurella) euglyptica Vred.,
Terebra (Myurella) myuros Lam., var. *obeliscus* Verd.,
Terebra (Myurella) oldhami Vred.,
Terebra (Myurella) quettensis Vred.,
Terebra (Myurella) protomyuros (Noetl.), (Restricted to Kama stages),
Terebra (Myurella) butaciana Mart..
Terebra (Myurella) intermedia Vred.,
Terebra (Noditerebra) samarangana Mart.,
Terebra (Hastula) hirasei Vred. (equivalent to an unnamed species from Japan),
Terebra (Hastula) pectinata Vred. (close resemblance to the living *T. acuminata* Gray),
Terebra (Hastula) lepperi Vred. (closely resembling *T. hirasei*),
Terebra (Duplicaria) noetlingi Vred.,
Terebra (Hastula) calamaria Vred. (closely resembling *T. strigillata* Linn.),
Terebra (Hastula) pagoda Vred.,
Terebra (Hastula) mayoi Vred.,
Terebra (Hastula) tittabweensis Vred. very close to *T. mayoi*),
Terebra (Hastula) irravadica Vred.,
Terebra (Hastula) stuarti Vred. (related to *T. iravadica*),
Terebra (Hastula) herklotsi Mart., var. *arundinea* Vred. (species from Java),
Clavatula (Perrona) birmanica Vred. (resembles the living *Cl. monile* from Australia),
Clavatula (Perrona) munga Noetl.,
Clavatula protonodifera Noetl.,
Surcula promensis Vred., (restricted to the Kama stage),
Surcula sethuramae Vred.,
Surcula karenaica (Noetl.),
Surcula thangaensis Vred.,
Surcula birmanica Vred. (resembles very closely *S. sismondae* Bell & Micht., from the Miocene of Piedmont),
Surcula (Pleurofusia) feddeni Noetl.,
Surcula (Pleurofusia) irravadica Vred. (probably a mutation of *S. feddeni*),
Surcula (Pleurofusia) phasma Vred.,
Surcula (Pleurofusia) scala Vred.,
Tritonidea (Cantharus) bucklandi (d'Arch.).
Pelurotoma fascialis Lam.,
Pelurotoma albinoides Mart., var .
Pelurotoma ickei Mart. (also in the Gaj of Cutch),
Pelurotoma (Hemipleurotoma) yenanensis (Noetl.) (also in the Nari of Sind),
Pelurotoma (Hemipleurotoma) bonneti Cossm.,
Pelurotoma (Hemipleurotoma) iris Vred.,
Pelurotoma (Gemmula) birmanica Vred.,
Pelurotoma (Gemmula) thyrsus Vred. (close to *Pl. gemmata* Hinds from the Indo-Pacific region),
Drillia pulcherrima Vred.,
Drillia ermelingi Mart.,
Drillia madiunensis Mart.,
Drillia protocincta Noetl. (also in the Garo Hills of Assam and the Pliocene of Java),
Drillia indica Vred.,
Drillia decemplicata Vred. (closely resembling *Dr. indica*),
Drillia dormitor Vred., (Almost identical with the living *Pleurotoma mediocris* Desh. from the Isle of Bourbon),

Drillia (*Brachytoma*) *tjemoroensis* Mart., *var.* (a characteristic Kama type; species from Java; same variety found in the Garo Hills of Assam.[71]),
Drillia (*Brachytoma*) *yabei* Vred. (close to *Dr. pinfoldi*) and var.,
Drillia (*Brachytoma*) *sarasvati* Vred. (very close to *Dr. pinfoldi*, Vred.),
Drillia (*Brachytoma*)*annandalei* Vred. (closely resembling *Dr. crenularis* Lam. from the coasts of India, Malaysia and Australia),
Drillia (*Brachytoma*) *yabei* Vred. (close to *Dr. pinfoldi*) and var.,
Drillia (*Brachytoma*) *reticulata* Vred. (close to *Dr. annandalei*),
Drillia (*Crassispira*) *constricta* Vred.,
Drillia gautama Vred.,
Drillia (*Crassispira*) *bataviana* Mart., var. (species from Java),
Drillia (*Crassispira*) *subbataviana* Vred.,
Drillia (*Crassispira*) *kamaensis* Vred.,
Drillia (*Crassispira*) *promensis* Noetl.,
Drillia (*Crassispira*)*subpromensis* Vred.,
Drillia (*Crassispira*) *tittabweensis* Vred.,
Drillia (*Crassispira*) *myaukmigonensis* Vred.,
Drillia (*Crassispira*) *irravadica* Vred.,
Drillia (*Crassispira*) *birmanica* Vred.,
Drillia (*Crassispira*) *constricta* Vred.,
Drillia (*Crassispira*) *dalabeensis* Vred., (very close to *Dr. harpularia* Desm from Australia),
Drillia (*Crassispira*) *cotteri* Vred., (Close to Dr. *geslini* Desm. from the Miocene of Piedmont),
Cypraea prunum Sow., *var. nasuta* Sow. (=Noetling's *Cypraea gransi* d'Arch.' & H.),
Bathytoma cataphracta (Brocchi),
Bathytoma herklotsi Mart.,
Mangilia elegantissima Vred.,
Mangilia (*Clathurella*) *martini* Vred.,
Mangilia (*Clathurella*) *quinqueangularis* Vred.,
Daphnella (*Raphitoma*) *birmanica* Vred.,
Conus (*Stephanoconus*) *sedanensis* Mart.,
Conus (*Leptoconus*) *vimineus* Reeve (=*C. palabuanensis* Mart; found also in the Mekran of Baluchistan),
Conus (*Leptoconus*) *bonneti* Cossm., (Karikal),
Conus (*Leptoconus*) *hanza* Noetl.,
Conus (*Leptoconus*) *yuleianus* Noetl.,
Conus (*Lithoconus*) *kyudawonensis* Vred.,
Conus (*Lithoconus*) *odengensis Mart.* (found also in the Gaj of Cutch).
Conus (*Lithoconus*) *myaukmigonensis* Vred.,
Conus (*Lithoconus*) *decollatus* Mart.,
Conus (*Dendroconus*) *hochstetteri* Mart.,
Merica sinensis Reeve, var. *laticosta* Kob.,
Merica verbeeki Mart.,
Merica promensis Vred.,
Trigonostoma bonneti Cossm.,
Trigonostoma birmanicum Vred.,
Trigonostoma speciosum Vred.,
Oliva (*Strephona*) *australis* Ducl., var. *indica* Vred. (found also in the Gaj of Cutch and the Garo Hills),
Oliva (*Strephona*) *kyundawensis* Vred. (probably a variety of the modern *O. auclosi* Reeve),[72]
Olivella minbuense Vred.,
Olivancillaria birmanica Vred.,
Olivancillaria (*Agaronia*) *nebulosa* Lam. (found also in the Gaj of Cutch and Sind),

[71] E. Vredenburg, Rec. 51, 329 (1921).
[72] E. Vredenburg, Rec. 54, 246 (1922).

Olivancillaria (*Agaronia*) *pagodula* Vred.,
Olivancillaria (*Agaronia*) *cossmanni* Vred.,
Ancilla (*Sparella*) *indica*, var. *arakanensis* Vred. (perhaps *A.* (*Sp.*) *birmanica* Vred.,
Cryptospira birmanica Vred.,
Ampullina (*cernina*) *callosa* (Sow.), (N.),
Ampullina obscura Sow. (N.),
Ampullina gracilior Noetl. (N.),
Sigaretus neritoideus Linne,
Mitra birmanica Vred.,
Mitra irravadica Vred.,
Mitra buddhaica Vred.,
Mitra granatinaeformis Mart.,
Mitra tittabweensis Vred.,
Mitra (*Cancilla*) *rembangensis* Mart. (a Java form; also probably found in the Gaj of Sind),
Mitra (*Cancilla*) *subacuminata* Mart. (Java),
Mitra (*Chrysame*) *kyaungonensis* Vred.,
Surcula (*Turricula*) *thangaensis* Vred.,
Surcula (*Turricula*) *minima* Vred.,
Clavilithes seminudus Noetl.,[74]
Clavilithes inopinatus (Cossm.),
Lathyrus (*Peristernia*) *gautama* (Noetl.),
Lathyrus (*Peristernia*) *promensis* Vred,
Lathyrus pseudolynchoides Vred.,[75]
Lathyrus iravadicus Vred.,
Latrunculus (*Eburna*) *lutosus* Lam. var.,
Hindsia neacolubrina (Noetl.),
Hindsia pardalis (Noetl.),
Ranella antique Vred.,
Ranella (*Pseudobursa*) *promensis* Vred.,
Cassidaria echinophora (Linn.), var. *promensis* Vred.
Pyrula (*Ficula*) *promensis* Vred.,
Rimella (*Dientomochilus*) *javana* Mart.,
Rimella (*Dientomochilus*) *promensis* Vred.,
Turritella angulata Sow.,
Turritella noetlingi Vred.,
Turritella leiopleurata Noetl. (N),
Turritella lydekkeri Noetl. (N.),
Vermetus javanus K. Mart. (N.),
Fossarus krausei Noetl. (N.),
Marginella (*Glabella*) *scripta* Reeve (N.),
Cancellaria inornata Noetl. (N.),
Ringicula turrita K. Mart. (N.),
Fusus promensis Vred.,[76]
Siphonalia (*Kelletia*) *kelletiformis* Vred.,
Nassa (*Cyllene*) *pretiosa* Vred.,[77]
Phos acuminatus Mart.,
Tritonidea praeundosa Vred.,
Tritonidea promensis Vred.,
Tritonidea heptagona Vred.,
Tritonidea (*Cantharus*) *bucklandi* (d'Arch.),
Tritonidea (*Cantharus*) *speciosa* Vred.,
Bela (*Haedropleura*) *orientalis* Vred. (an unusual form)[78]
Melongena (*Pugilina*) *praeponderosa* Vred.

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[73] Rec. 54, 251 (1922).
[74] Rec. 51, 297 (1921).
[75] Rec. 55, 60 (1923).
[76] Rec. 55, 54 (1923).
[77] Rec. 55, 69 (1923).
[78] Rec. 55, 75 (1923).

ARTHROPODA.

Balanus (Chirona) birmanicus Withers,
Callianassa birmanica Noetl. (N).

At Padaukpin and Banbyin the Kama Clay attains a thickness considerably more than 1,200 feet, and is characterised by oil seepages ;[79] here it underlies the Turritella Sands with *T. angulata* (Akauktaung stage) and frequently shows intercalated contortion. Among the fossils found are *Lithodomus* sp., *Leda virgo* Mart., *Corbula socialis* Mart., *Pyrula (Ficula) promensis* Vred., *Natica obscura* Sow., *Lucina globulosa* Desh. (Miocene of Italy; also at the base of the Padaung stage in Minbu), *Balanus (Chirona) birmanicus* With., *Carcharodon megalodon* Ag., and *Hemipristis serra* Ag.

The Upper Prome stage.—In the Prome district the Kama Clay probably includes the Upper Prome stage (Theobald's "Division B"), following the Lower Prome (Singu stage) in normal sequence and having at its base a bed known as the Prome Sandstone, which is a passage horizon between the Lower and Upper Prome subdivisions, *i.e.*, between the Singu and Kama stages. This bed is well exposed opposite the town of Prome and is characterised by the abundance of the Lamellibranch *Meretrix (Cytherea) promensis* Theob., a form which ranges up into higher beds and may be identical with the living *C. florida* Lam.; it was at first erroneously identified with the living *C. erycina* Favanne.[80] The fauna from this bed (Noetling's "zone of *Cytherea erycina*") is as follows:

LAMELLIBRANCHIATA.

Meretrix (Cytherea) promensis Theob. (abundant).

ACTINOZOA.

Ceratotrochus alcockianus Noetl. (N.),
Flabellum distinctum M.-Edw.,
Pecten (Chlamys) articulatus Sow.,
Cardita protovariegata Noetl. (N.),
Meretrix (Dione; Pitar) protolilacina (Noetl.), (N.),
Meretrix (Tivela) protophilippinarum (Noetl.) (N.),
Dosinia protojuvenilis Noetl. (N.),
Tellina grimesi Noetl. (N.).

GASTROPODA.

Vermetus javanus K. Mart. (N.),
Natica callosa Sow., (N.),
Natica obscura Sow. (N.),
Sigaretus neritoideus Linne, (N.),
Ranella (Pseudobursa) promensis Vred.,
Latrunculus (Eburna) lutosus Lam.,
Melongena (Pugilina) praeponderosa Vred.,
Ancilla (Sparella) birmanica Vred.,
Terebra (Subula) noetlingi Vred.,
Consus (Lithoconus) odengensis Mart., var. *birmanica* Vred.

[79] Rec. 38, 273 (1909).
[80] Rec. 51, 244 (1920).

ARTHROPODA.

Batanus (Chirona) birmanicus Withers.

Some eighteen miles above Prome, in the Kama section *Meretrix promensis* is found in the greatest profusion from the bottom to the top of the Upper Prome stage.

From a reef in the Irrawaddy opposite Padaung in the district of Prome the following fossils have been collected from beds of unknown horizon but belonging probably either to the Upper or Lower Prome group:

LAMELLIBRANCHIATA.[81]

Tapes protolirata Noetl.,
Meretrix (Dione; Pitar) protolilacina (Noetl.),
Solarium sp.,
Meiocardia sp.,
Cucullaea protoconcamerata Noetl.,
Arca sp.

GASTROPODA.

Turritella angulata Sow.,
Conus (Lithoconus) ineditus Mich.

The Kama of north Minbu.—Southwards, in the Henzada district, the Kama stage, as well as the Singu and Padaung stages, is absent, the Akauktaungs, with perhaps the Pyalos lying directly and unconformably upon the Sitsayam Shales. North of the Thayetmyo district the Kama and overlying Pyalo stages become obscure. In the Ngahlaingdwin locality of north Minbu, two fossil beds, 150 feet apart, probably represent either the Kama or Pyalo faunas; the lower contains *Cyrena (Batissa) birmanica* Vred., and *C. (B.) kodaungensis* Noetl., the upper *C. (B.) birmanica* and unidentifiable species of *Arca, Turcica* and *Paracyathus*. The associated beds comprise very soft, blue-grey sandstones frequently current-bedded and sometimes ripple-marked, alternating with light blue shales often stained with ochre.

The Kama stage in the Yenangyaung and Singu oilfields.—The rich Kama fossil zones near Dalabe, Thanga and other localities in Thayetmyo are probably represented in the oilfields of Yenangyaung and Singu by sandstones, shales and arenaceous limestones with very poor fossil contents; in both areas the beds constitute the upper section of the Pegu sequence and would seem to represent some portion of the Kama stage.

From one of the Burmah Oil Company's wells in the Yenangyaung field from an horizon about 1,300 feet below the local top of the Pegu, was obtained the following shallow-water fauna (Noetling's zone of *Anoplotherium birmanicum*"):

LAMELLIBRANCHIATA.

Pecten (Chlamys) articulata Sow.,
Lithodomus sp.,

[81] Rec. 36, 132 (1907).

Arca bistrigata Dunker (N.),
Meretrix (Tivela) protophilippinarum (Noetl.),

PISCES.

Myliobates sp.,
Sphyrna prisca Ag (?), (M. Stuart),
Siluroid gen.,
Python cf. *molurus* Linne, (N.),
Crocodilus palustris Less., (N.),
Garialis gangeticus Gmel. (N.),
Upper molar of a small member of the Tragulidae,
Lower molar of a selenodont suine, *Dorcatherium* sp.

The larger shells were broken and the bones rolled. Vredenburg places,[82] this fauna at approximately the same level as the Prome Sandstone ("*Cytherea promensis*" zone) at the Upper Prome or Kama sequence in the Prome district. According to this, the Pegus exposed at Yenangyaung must all belong to the Kama Clay or to younger stages, a conclusion in accord with the writer's opinion regarding the small, crushed, shallow-water marine fossils discovered by him in small isolated patches at two or three higher horizons in the Yenangyaung dome.[83] From a bed in the Natsin Yo, very close to the above mentioned bed, come:

FORAMINIFERA.

Rotalia sp. (plentiful).

ACTINOZOA.

Dendrophyllia sp.

LAMELLIBRANCHIATA.

Arca bistrigata Dunk. (N.),
Arca (Anomalocardia) theobaldi Noetl. (equivalent to "*Anadara craticulata*" Nyst. and Noetling's "*Arca burnesi*" d'Arch.), (N.),
Arca (Anomalocardia) myoensis Noetl. (N.),
Nucula alcocki Noetl. (N.),
Leda virgo Mart. (N.),
Cardita variegata Noetl. (N.),
Cardita cf. *visquesneli* d' Arch. probably *C. (Venericardia) noetlingi* Cott.,
Lucina neasquamosa Noetl. (N.),
Venus protoflexuosa Noetl. (N.),
Venus (Omphaloclathrum) puetpera Linn., var. *aglaurac* Brongn.,
Meretrix (Tivela) protophilippinarum (Noetl.),
Meretrix (Dione; Pitar) protolilacina (N.),
Meretrix (Tivela) dubiosa (Noetl.) (N.),
Tapes protolirata Noetl. (N.),
Dosinia protojuvenilis Noetl. (N.),
Corbula (Bicorbula) prototruncata Noetl. (N.).

GASTROPODA.

Basilissa lorioliana Noetl. (N.),
Solarium maximum Phillipi (Plentiful), (N.),
Turritella angulata Sow. (plentiful),
Calyptraea rugosa Noetl. (N.),
Natica obscura Sow. (N.),

[82] (N)—determinations by Noetling unrevised.
[83] Mem. 40, 59 (1912).

Natica gracilior Noetl. (plentiful), (N.),
Sigaretus neritoideus Linne (N.),
Olivelle minbuensis Vred.,
Terebra samarangana Mart.,
Terebra (Subula) noetlingi Vred.,
Surcula karenaica (Noetl.).

ARTHROPODA.

Balanus (Chirona) birmanicus Withers.

PISCES.

Sphyrna prisca Ag.,
Fish otoliths.

From a higher horizon in the Taung-hnit-lon. not far below the upper boundary of the Pegu, the following have been found:

ACTINOZOA.

Dendrophyllia sp. (plentiful).

ECHINOIDEA.

Cidaris sp.

LAMELLIBRANCHIATA.

Ostraea digitata Eichw., var *rohlfsii* Fuchs,
Ostraea papyracea Noetl. (N.),
Chlamys articulata Sow. (plentiful),
Arca nannodes K. Mart. (N.),
Arca (Anomalocardia) theobaldi Noetl. (plentiful), (N.),
Leda virgo K. Mart.,
Cardita cf. *visquesneli* d'Arch. (plentiful) (probably *C. (Venericardia) noetlingi* Cott.),
Meiocardia sp.,
Lucina neasquamosa Noetl. (N.),
Meretrix (Tivela) protophilippinarum (Noetl.),
Meretrix (Dione) arrakanensis Noetl. (N.),
Tellina hilli Noetl. (N.),
Corbula socialis K. Mart.,
Corbula prototruccata Noetl. (N.).

GASTROPODA.

Solarium maximum Phillipi (N.),
Turritella angulata Sow. (plentiful),
Natica obscura Sow. (N.),
Natica gracilior Noetl. (N.),
Cassidaria (Galeodea) echinophora Linne, var. *monilifera* Noetl.,
Pyrula (Ficula) condita Brongn. var. *singuensis* Vred.,
Lathyrus (Peristernia) sp.,
Melongena pseudobucephala (Noetl.),
Olivella minbuense Vred.,
Terebra samarangana Mart.,
Surcula scala Vred.,
Conus (Lithoconus) ineditus Mich. (close to *C. malaccanus* Hwass),
Conus (Conospira) galensis Noetl.

ARTHROPODA.

Balanus (Chirona) birmanicus Withere,

Sphyrna prisca Ag.,
Myliobates sp. (same as figured by Noetling.).[84]

SILUROID.

FISH OTOLITHS.

There are many fossiliferous limestones in what is thought to be the equivalent of the Kama stage in the Singu field, but outcrops are few, the yield of fossils is small, and no appreciable collections appear to have been made. *Meretrix* (*Tivela*) *protophilippinarum* has been recognised and species of *Arca*, and *Conus*; the bed containing Noetling's *Cardita tjidamarensis* some 1,400 feet below the top of the series, is probably the approximate lower limit of the stage.[85]

The Kamas of Pakokku and Myingyan.—In northeast Pakokku, to the north of Ingyin Taung, a rich and unusual fauna of corals, bryozoa, echinoids and lamellibranchs has been obtained from lenticles of limestone found occasionally in a succession of alternating shales and sandstones which replaces a massive sandstone exposed in the Ingyin Taung scarp itself. Several of the species are new : with one or two exceptions they have not been recorded from the Pegu of Burma, but 10 of them are identical with or closely allied to Miocene forms from Egypt (marked " E "), Java (" J ") or India (" I "):[86]

BRYOZOA.

Cellepora sp.

ARTHROPODA.

Balanus sp.,
Neptunus sp.

CRINOIDEA.

Isis compressa Dunc. (I),
Isis sp. 1 Dunc. (I),
Isis cf. sp. 2 Dunc. (I),
Isis sp. nov.

ACTINOZOA.

Stylophora digitata Pallas (J),
Calamophyllia sp.,
Leptoria sp.,
Hydnophora sp.,
Orbicella defrancei E. & H. (cosmopolitan Miocene form),
Stylocoenia tuberculata Greg. (E.),
Prionastraea lyonsi Greg. (E.),
Prionastraea sp.,
Latimeandra sp.,
Pachyseris sp.,
Porites sp.,
Goniopora sp.,

[84] Pal. Ind., New Ser., Vol. I, No. 3, Pl. 25 (1901).
[85] Rec. 53, 328 (1921).
[86] Rec. 60, 89 (1927).

ECHINOIDEA.

Brissus cf. *declivis* Herkl. (J.),
Cidaris spines.

LAMELLIBRANCHIATA.

Modiola affinis K. Mart. (J.),
Modiola sp.,
Pecten cf. *zitteli* Fuchs (E.),
Pecten sp.,
Ostraea sp.,
Lima protosquamosa Noetl. (Singu stage species).

The indications appear to be those of the basal part of the Upper Pegu.

From Kwatalin, 21 miles south of Taungtha in the Myingyan district, have been collected *Vicarya collosa* Mart. and *Meretrix (Cytherea) promensis* Theob., and indications probably of the presence of the Kama stage. Taungtha itself has yielded *Balanus (Chirona) birmanicus*.[87]

The Pyalo stage.—The Pyalo stage, first recognised in Thayetmyo on the eastern side of the Irrawaddy, has been identified only in two or three other not very distant localities. To what extent this restricted distribution is due to limited deposition or to scanty remains is not clear. The beds of the type area were at first grouped as the basal portion of the Akauktaung stage, and there is, in fact, no very serious incentive to remove them from that position and give them the status of a separate stage. The Pyalo is thought to be the equivalent of the Upper Gaj of Sind and perhaps also of the Someswari fauna on the Garo Hills in Assam ;[88] its representative in Java is considered to be the Njalingdung stage, while its approximate European equivalent is the Burdigalian. Vredenburg gives the thickness of the Pyalos as about 1,500 feet of sandstones, pebble beds and shales. Clegg would prefer to include the Pyalo beds as part of the Kama stage.[89]

In the Pyalo-Kwetha section on the east bank of the river in the Thayetmyo district, some 2,200 feet of Pegu beds are exposed. Among them a fossil bed containing many large specimens of *Ostraea latimarginata* Vred., one of the principal zone fossils of the uppermost Gaj in Cutch, Kathiawar and Sind and occurring also in Persia, has been found by H. J. Davies, occurring some 900-1,000 feet above beds carrying the Kama Clay fauna.[90] The same Pyalo beds with the same oyster are found on the opposite side of the river above the town of Kama.[91] Here the only recognisable fossils are the *Ostraea* and some otoliths, occurring at an horizon which is 800-1,200 feet above beds containing the Kama stage fauna. It is probably this locality in which Stuart found species of a *Turritella* allied to *T. djadjariensis*

[87] Rec. 36, 138 (1907).
[88] E. Vredenburg, Rec. 51, 330 (1921).
[89] Mem. 72, 169 (1938).
[90] E. Vredenburg & M. Stuart, Rec. 38, 128 (1909).
[91] Rec. 51, 239 (1921).

Mart., a Java form occurring also in the Pyalo-Kwetha seciton in company with *Ostraea latimarginata.* From the Pyalo stage at Sitsaba in southern Thayetmyo come *Phos acuminatus* Mart., and *Eburna lutosa* Lam.[92]

The third locality at which the Pyalo stage is seen lies in the northern half of Minbu, at Myaung-u; from near the top of the Pegu sequence here come: *Terebra (Duplicaria) myaunguensis* Vred. (a form very close to *T. woodwardiana*), *T. (Myurella) promensis* Vred., *Turritella pinfoldi* Vred., *and Conus (Lithoconus) pamotanensis* Mart., as well as the type lamellibranch, *Ostraea latimarginata.*[93]

The Pyalo stage may possibly underlie the Akauktaung stage in the north of Henzada in the form of coarse, fossiliferous, ridge-forming grits.[94] A fragment of *Ostraea latimarginata* has been found but in circumstances which do not preclude the possibility of its being derived; its associate in Sind, *O. gingensis,* is abundant in these Henzada grits.[95]

In Upper Burma the Pyalo stage may perhaps be represented by some variegated beds or grey sandstones and shales underlying the topmost Pegu bed which is a peculiar white sand. These beds, which have been noted in the oilfields of Yenangyaung, Singu, Yenangyat, and Minbu, and elsewhere, consist usually of a ragstone of impure clay or sand, often crowded with crushed and fragmentary specimens of *Cyrena (Batissa).* These brackish or fresh water shells are not confined to the highest Pegu but are also found along the actual boundary between the Pegu and the Irrawadian. In the Yenangyaung dome four species of this genus have been differentiated, *C. (B.) crawfurdi* Noetl., *C. (B.) yedwinensis* Pasc. (perhaps a variety of *crawfurdi*), a long form known as *C. (B.) birmanica* Vred., and the large *C. (B.) kodaungensis* Noetl.; the first two are found about 300 feet below the local base of the Irrawadian, while the two beds occur along the Peku-Irrawadian boundary itself (see below). The suggestion that these *Batissa* beds may be an estuarine equivalent of the Pyalo of Lower Burma is based on their stratigraphical position, which is estimated to be 1,400-1,500 feet above the youngest fossil band of the Singu stage and therefore probably above the upper limit of the Kama stage. In the Sabe area or northern end of Yenangyat, the thickness of the Supra-Kama Pegu beds—comprising the Pylao or Akauktaungs, or both—has been estimated at 300-400 feet; these beds here form a fluviatile zone with fossil wood and selenite, overlain by the White-sand.[96] In the Shinmadaung area the place of the Pyalo stage appears to be filled by volcanic beds.

The Akauktaung stage.—The Akauktaung stage is named after the celebrated carved rocks on the Irrawaddy at the extreme northern

[92] Rec. 55, 69-70 (1924).
[93] Mem. 72, 77 (1938).
[94] Rec. 41, 245 (1911).
[95] E. Vredenburg, Rec. 51, 252 (1921).
[96] G. de. P. Cotter, Rec. 38, 303 (1909).

point of the Henzada district. It is regarded as of Vindobonian if not of somewhat younger age, and is probably the marine equivalent of the basal portion of the Irrawadian series. For reasons which have been already generally discussed (p. 1688) it has been included as the topmost member of the Pegu series, on the understanding that the plane of division between the Pegu and Irrawadian is a facietal one drawn for convenience, and not a chronological one. The Akauktaungs were at first correlated with Theobald's "Mogaung Sands" cropping out north of Allanmyo in the district of Thayetmyo. These beds, 75-250 feet thick, consist mainly of fluviatile beds of Irrawadian aspect but pass down into marine basal beds known as the "Turritella Sands,[97] which taxially form part of the Akautang stage.

In the type area of Henzada, the Akauktaung stage has been described as about 4,000 feet in thickness. Whether this succession, however, includes the Pyalo stage as well, depends upon the contingency of a fragment of *Ostraea latimarginata* obtained from the beds being of secondary origin and derived from an older deposit,[98] and upon the zone value of that species. The beds are coarse grits varying in colour from yellow to red and occasionally conglomeratic, soft yellow sandstones differing from the Irrawadian only in their marine fossil contents, occasional blue shales and a few bands of hard, calcareous sandstone which, however, quickly weather to loose yellow sand. The coarse fossiliferous grits, which are ferruginous in places, give rise to ridges, while the loose weathered sand produces a gently undulating country, but the scenery as a whole is of Pegu aspect. Fossils are plentiful throughout the grits and are characterised by the abundance of the genus *Ostraea*. From the basal grits near Yethyauksan Stuart has collected *O. gingensis* (*Schlotheim*), *O. digitata* Eichw. *O.* (*Alectryonia*) *virleti* Desh.,[99] all of them amongst the characteristic fossils of the Makran (Talar stage) series of Baluchistan. The Akauktaung stage, if Vindobonian, would correspond to the Java Tji Lanang stage. In addition to the *Ostraeae* the following have been recorded: *Arca* (*Anadara*) *craticulata* (*Nyst.*), *Meretrix* (*Cytherea*) *promensis* Theob., *Meretrix* (*Tivela*)*dubiosa* (Noetl.), *Turritella* (*Torculoidella*) *angulata* Sow. and *Conus* (*Lithoconus*) *odengensis* Mart., all of them common Pegu fossils.[100] In Henzada the beds, whether belonging to the Akauktaung stage alone or to both the Akauktaungs and Pyalos, overlie the Sitsayan Shales with an angular unconformity. This discordancy may decrease considerably northwards and in the Padaukpin area of Thayetmyo the "*Turritella* Sands" lie upon the Kama Clay; between Nathe and Aukmanein the Akauktaung bds contain, in

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[97] It seems doubtful whether Theobald (Mem. 10, 260 (1873)) intended to include any marine basal beds within the lower boundary of his group; no marine fossils are mentioned in his sections except some shark's teeth, chelonian plates and rolled oysters, all of which may have been derived.

[98] E. Vredenburg, Rec. 51, 252 (1921).

[99] There was also collected a form described as probably the equivalent of *O. crassicostata* G. B. Sow.; the latter, however, is believed to be synonymous with *O.* (*Alectryonia*) *virleti* Desh.

[100] Murray Stuart, Rec. 41, 240 (1912); E. Vredenburk, Rec. 51, 281-294 (1912).

addition to marine mollusca and numerous sharks' teeth, fossil roots of a species of palm.[101]

Chronologically, the unconformity at the base of the Akauktaungs is probably the approximate equivalent of that of the base of the Irrawadian series a little further north. On the right bank of the Irrawaddy in Henzada the Akauktaung beds are folded in a broad syncline, overlying Sitsayan Shales on the west and faulted against the same rocks to the southeast; isolated patches of the Akauktaung rocks occur to the southwest of the main exposure. On the east side of the faulted anticline of Sitsayan Shales against which the Akauktaungs are faulted, the latter rocks are again seen and cross the Irrawaddy to the Prome side where they underlie the Irrawadian; traced northwards the outcrop of the Akauktaungs finally disappears beneath alluvium a few miles below Shwedaung.[102] Fossils are pentiful throughout the grits.

The White sand and Red Bed.—In Upper Burma the place of the Akauktaung beds appears to be taken by a peculiar White Sand which forms the uppermost limit of the Pegus in the oilfields and elsewhere and owes its brilliant whiteness to the presence of kaolin derived from felspar, grains of which are also plentiful in the rock; it is often rich in flakes and layers of selenite, and in a few places fragments of wood partially replaced by iron oxide are to be found. No such bed is found in Lower Burma, and this fact lends colour to the supposition that its weathered felspar contents represent a volcanic ash derived from Popa and other volcanoes of the north. Owing to its conspicuous colour, it is an easily identifiable bed and can be seen a long way off. In the Wetchok-Yedwet dome its place is taken by an arenaceous limestone containing a large proportion of sand, which consists mostly of quartz in large, moderately rounded grains, a little orthoclase and plagioclase and some green pleochroic hornblende. This rock is stained with thin, brown, concentric spheroidal shells of iron and manganese oxide which weather more readily than the rest of the sediment and produce a surface ornamented with a mutually interfering systems of concentric rings, the whole structure forcibly imitating the "orbicular structure" seen in that form of diorite known as corsite or napoleonite.

The White Sand is closely associated with another conspicuous bed, a red bed or ferruginous conglomerate at the base of the Irrawadian; the two types in fact sometimes alternate and both in some places, like the beds at a slightly lower level, contain specimens of *Batissa*. In the Yenangyaung field, the species at this level, *B. birmanica* Vred. and *B. kodaungensis* Noetl., differ from those found lower down, but whether this is universally true is not known; in the southern part of the dome, at Minlindaung, the shells are crowded together, in good preservation and mostly with valves united.[103] Another species distinguished by its unique size *Cyrena* (*Batissa*) *sethuramae* Vred.,

[101] Murray Stuart, Rec. 38, 272 (1909).
[102] Murray Stuart, Rec. 41, 244 (1912).
[103] E. H. Pascoe, Mem. 40, 63 (1912).

the largest *Batissa* on record, extinct or recent, was first discovered by the writer in the Minbu anticline and assigned to the species, *kodaungensis,*[104] and afterwards found by Sethu Rama Rau in the Yenangyat region ; it has a length something like 250 mm. In the Yenangyat region it occurs in association with the fresh-water form *Taia* (*Rivularioides*) *spinifera* Vred.; in the northern portion of this fold *Cyrena* (*Batissa*) *kodaungensis* and a species of *Melania* are recorded at this horizon.[105] The thickness of the White Sand varies from about 10 to 50 feet. Along the western side of the Singu fold it is 45-50 feet thick and contains many ferruginous intercalations before it is finally replaced by the basal ferruginous conglomerate or earth-bed of the Irrawadian ; the intercalations themselves grade from a brick-red sandstone to a lateritic conglomerate. Along nearly the whole of the eastern limb of the Yenangyat anticline the White Sand is absent.

NORTHERN EXPOSURES OF THE PEGU.

As already noted, when traced northwards, each stage of the Pegu series assumes an estuarine and ultimately fluviatile facies. This change, which takes place earlier in the lower stages than it does in the upper, makes it more and more difficult and finally impossible to distinguish between the subdivisions. Some of these northern localities merit a brief reference.

In the Ngape area of south Minbu the Pegu horizons above the Singu stage are mostly unfossiliferous and have not yet been subdivided. In north Minbu, south of Ngahlaingdwin, the Pegu series falls into two divisions, the boundary between them corresponding approximately to the boundary between the Oligocene and Miocene and being characterised by a ferruginous gritty sandstone of varying thickness which passes laterally into a ferruginous pebbly conglomerate with lenticles of coal. Above this horizon, which probably marks an unconformity, the Upper Pegu consists mainly of sandstones, grits and conglomerates with subordinate shales of a shallow-water type poor in fossils.[106] In the country northwest of Myaing, in north Pakokku, three divisions of the Pegu appear possible, a lower of coarse sandstone with fossil wood, corresponding probably to the Shwezetaw, a middle consisting of alternations of shale and sandstone with occasional beds of broken fossils, the equivalent of the Padaung and perhaps the Singu stages, and an upper of current-bedded sandstones with fossil wood, representing the rest of the Pegu sequence. In the immediate vicinity of Myaing the Pegus, if present at all, are almost completely overlapped by the Irrawadian and appear to be reduced to about 1,000 feet ; from these beds probably comes the *Otodus appendiculatus* found by Cotter.[107]

In central Pakokku the Pegus, some 6,600 feet thick, are described by Cotter as grading from estuarine below to fluviatile above but as

[104] Rec. 36, Pl. 20, fig. 2 (1907).
[105] G. de. P. Cotter, Rec. 38, 302 (1909).
[106] G. de. P. Cotter, Mem. 72, 77 (1938).
[107] Murray Stuart, Rec. 38, 294 (1909).

consisting from top to bottom of current-bedded sandstones and conglomerates.[108] The only line of subdivision is the median bed of red conglomerate which divides the series into about equal proportions. Above it the beds are entirely fluviatile, consisting of current-bedded, poorly stratified sandstones with fossil wood and occasional occurrences of *Batissa crawfurdi*; one locality has yielded *Cyrena borneensis* Bottg. These beds are scarcely distinguishable from the Irrawadian above, the chief difference being the looser and softer nature of the latter and their gleaming white appearance in fresh sections, the upper Pegu sandstones being of a light cream colour, with rather more definite bedding planes and frequently characterised by "cannon-ball" concretions.

In north Pakokku even the median ferruginous bed has died out. Here also it is no longer possible to separate the Irrawadian from the Pegu, since the red earth or conglomerate boundary of the more southerly areas becomes duplicated more than once, and it is evident that we have arrived at an Upper Pegu land area. Fossil wood in the Pegu is sometimes carbonised, sometimes silicified; logs up to 25 feet in length and 3 feet diameter are recorded. The highest Pegu beds—perhaps the Pyalo stage—in the Shinmadaung area of Pakokku include volcanic types; these overlie soft sandstones and clays of Kama age, below which come some variable beds assigned to the Singu.

The Pegus of the northern half of the Shwebo district are described by Iyer as varying from fragile clay or shale to alternations of fine-grained bedded sandstone and clay, or to a hard, fine-grained sandstone with thin bands of grey limestone. The limestone is composed of grains of quartz, chlorite and biotite in a calcareous base, and passes into a calcareous sandstone with iron-ore and sericite in addition. A long thin dyke of a rock intermediate between an andesite and a dolerite intrudes these beds which in places pass up gradually into the Irrawadian series.

In northern Myingyan, Sagaing and Meiktila, the Pegu rocks are described as an alternating series of sandstones and shales in which the former predominate. In a general way the beds can be distinguished from the younger Irrawadian by the greater hardness and compactness of the sandstones, the comparative infrequency of current-bedding therein, the occasional presence of thin calcareous bands, the frequent presence of selenite, and in a few isolated localities the occurrence of specifically indeterminable marine fossils, but there is no distinct boundary between the two formations. The general change from estuarine to fresh-water conditions is markd by no red bed and only occasionally and locally by unconformity. The rocks are folded in a series of broken anticlines and synclines arranged *én echelon*, the crests of the anticlines forming intermittent hill ranges, of which Taungtha is the highest and most characteristic.[109]

[108] Mem. 72, 83 (1938).

[109] Gen. Rep. Rec. 59, 68 (1926).

Some 25 miles northeast of Sattein, in the district of Myingyan, is a range of hills culminating in the hill of Taungtha, a conspicuous landmark inferior only to the volcano of Popa. It is occupied by Pegu and Irrawadian beds, folded in a N.N.W.-S.S.E., asymmetric anticline, with a steep and faulted southwesterly limb and a very gentle northeasterly limb. The beds are contorted and to some extent metamorphosed by pressure, sandstones predominating on the whole over clay beds; slabs of limestone are occasionally seen. Marine fossils are scarce but include fragments of *Turritella, Ostraea, Balanus (Chirona) birmanicus* Withers, a simple hexacorallid (? *Ceratotrochus*), and a spine of a doubtful *Myliobates*. *Vicarya callosa* Mart. and *Meretrix (Cytherea) promensis* Theob. have been collected 21 miles further south.[110] The curious manner in which the Pegu rocks of the middle part of the eastern flank of Taungtha hill range and the western flank of Mingontaung have been scoured away, is thought by Clegg to have been accomplished by the early Irrawaddy river whilst in process of changing its course from the Samon-Sittang valley to its present site.[111]

In faulted domes and anticlines some presumed exposures of Upper Pegus occur in north Sagaing, the predominant type of bed being a fawn or greenish grey, coarse, current-bedded, loosely consolidated sandstone. In it are lenses and thin discontinuous layers consolidated herent sandstone, and frequent intercalations of fawn or greenish shales which are sometimes calcareous. A common rock is a thinly-bedded grit with numerous rounded concretions or quartz pebbles. Fossil wood is not uncommon in the beds. Water emerging from them is usually heavily charged with alkaline salts which are precipitated to form the *sapaya* or " soap-sand ".[112]

A Pegu inlier occurs at Lebya in Meiktila.

In the southern part of the district of Shwebo, within a large tract of Irrawadian rocks a few isolated patches have been mapped as Pegu for purely lithological reasons; in some parts of the Shwebo district there is a gradual passage from the Pegu up into the Irrawadian.[113] Petroleum occurs in the Kyunhla township, where a few wells have been sunk.

Coal bearing Tertiaries on the east side of the Mu river near Wuntho belong perhaps to the Pegu series; they are succeeded westwards by Irrawadian beds.[114]

Some low ranges in the Jade Mines area are made up of sandstones, shales and conglomerates, with very thin seams of coal or lignite and occasional bands of finely jointed, carbonaceous limestone. In some places the beds are almost vertical and a considerable thickness must be exposed. The sandstones vary in colour but are

[110] Rec. 36, 132, 149 (1907).
[111] Gen. Rep. Rec. 59, 68 (1926).
[112] Gen. Rep. Rec. 62, 121-122 (1929).
[113] Gen. Rep. Rec. 67, 49 (1933).
[114] E. Noetling, Rec. 27, 119 (1894).

often bluish grey ; in texture they are coarse to medium and sometimes pebbly. They contain a varied assemblage of minerals, as grains in a siliceous matrix. Quartz and felspar (both orthoclase and plagioclase) predominate, but grains of epidote, glauconite, chlorite and serpentine are quite common ; small grains of graphite and graphite-schist are also present and in some sections particles of jadeite, muscovite, biotite, hematite, chromite and calcite.[115] At Hweka and other places the conglomerate is rich in boulders of jadeite and includes various types of serpentine, peridotite, amphibolite and other ancient rocks of the neighbourhood. The shales are generally carbonaceous and have yielded small Globigerinidae. Some badly preserved dicotyledonous leaves of *a Laurus* found by Bleeck in the coal and described by J. Schuster under the name of *Tetranthera hwekonensis*, prove that the beds, which probably form a continuous outcrop between Hweka and Nanion, are of Tertiary age ;[116] trunks of dicotyledonous fossil wood have also been noted in the vicinity. The beds were regarded by Noetling as Miocene (Pegu), but their precise age is not clear.

Arenaceous samples of the Tertiary rocks from the Jade Mines area have been examined by Majeed of the Assam Oil Company's staff, as to their heavy mineral contents ; some of the slides were found to be comparable to those of rocks from the Tipam, Surma and Barail series of Assam.[117]

Pegu beds are exposed in good sections along the Shadu, Tagam, Hkuma and Hkada streams in northwest Myitkyina.[118] With occasional interbedded layers of shale or argillaceous material, the predominant beds are well-bedded, greyish, greenish, pale yellow or reddish sandstones sometimes with black carbonaceous streaks, in some places finely laminated, in others coarse and pebbly. In the sandstones and the carbonaceous shales well preserved fossil leaves have been found. About 10,000 feet of these beds are exposed in the Shadu Hka. In the Kuma and Hsamshing Hkas the junction of these beds with the crystalline schists and serpentines is faulted. From their heavy mineral residues, these Pegu beds would appear to correspond to the Barail series (Laisong and Jenam stages) of Lower Assam or the Coal Measures (Naogaon and Baragolai stages) of Upper Assam, both of which series are thought to be the equivalents of the combined Pondaung (Laisong and Shwezetaw—" Jenam ") stages.

The Pegus of the Pegu Yoma.—Of the main mass of the Pegu beds stretching from Rangoon to Mandalay Theobald surveyed only the southern half, up to the middle of the Thayetmyo district. The only attempt at subdivision made by him was that affecting the westerly margin of this area where it is traversed by the Irrawaddy in Prome and Thayetmyo. Of the more central and eastern portions of this wide tract of the Pegu Yoma, including the watershed between the Irrawaddy and Sittang rivers, there is little information, and to what

115 Gen. Rep. Rec. 62, 109-110 (1929).
116 Reference as *T. Hwekonsis* (W. G. Bleeck), Rec. 36, 257 (1908).
117 Gen. Rep. Rec. 66, 83 (1932).
118 Gen. Rep. Rec. 66, 87 (1932).

extent subdivision of the Pegu series is possible in these parts is not known. Theobald's warning that "although many of its beds are rich in fossils in a good state of preservation, it often displays a great thickness of beds in which fossils are either absent or ill-preserved", has been justified by our failure hitherto to effect any widespread and satisfactory subdivision in the northern half of this great Pegu outcrop.

In some respects the name, Pegu, might be regarded as unfortunate for the series of rocks now being considered since the main mass of the Pegu Yoma is largely devoid of organic remains.[119] In the western parts of Yamethin and the contiguous portions of Magwe and Meiktila, the Pegu rocks are described as alternations of soft pepper-and-salt sandstones, sandy clays and bluish thin-bedded shales, in varying proportions, with lenticular bands of limestone or calcareous sandstone, especially along a belt west of Dalanyun; some of these calcareous bands show cone-in-cone structure.[120] The beds are sharply folded into irregular anticlines and synclines along N.N.W.-S.S.E. axes, and in places are much disturbed and contorted; a large strike fault is recorded south of Dalangyun. Forming the back-bone of the Yoma, the Pegu beds are folded into small rising and pitching anticlines and synclines which can be traced along their strike only for short distances; one of the larger synclines has been traced for about ten miles.

So far, only two localities have yielded good fossil horizons, one of which was discovered by Captain Walker some 3,000 feet below the Irrawadian boundary in the country south of Kontha in the north-east of Thayetmyo; the fauna, which appears to be that of the Kama stage, is made up for the most part of minute lamellibranchs, the remainder consisting of a species of *Dendrophyllia* and a few gastropods and fish teeth.[121] The other locality, near Myauknigon also in Thayetmyo, rewarded a search by A. H. M. Barrington with the following:[122]

ECHINOIDEA.

Cidaris spines.

GASTROPODA.

Clavilithes seminudus Noetl.,
Nassa (Cyllene) cf. *varians* Cossm.,
Conus (Lithoconus) odengensis Mart.,
Surcula (Pleurofusia) phasma Vred.,
Drillia (Brachytoma) buddhaica Vred.,
Drillia (Brachytoma) yabei Vred.,
Pleurotoma cf. *ickei* Mart.,
Merica promensis Vred.,
Rimella (?) *javanus* Mart.,
Natica (Naticina) aff. *blainvillei* Duclos., var. *Indica* Vred.,
Olivancillaria (Agaronia) pagodula Vred..

[119] Gen. Rep. Rec. 58, 47 (1925).
[120] Rec. 60, 83 (1927).
[121] Gen. Rep. Rec. 58, 47-49 (1925)
[122] Rec. 61, 19 (1929).

LAMELLIBRANCHIATA.

Meretrix (*Tivela*) *protophilippinarum*, var. *orbicularis* Vred.,
Ostraea sp.

Elsewhere, from four or five localities a few fossil fish teeth, indeterminable lamellibranchs and gastropods, and bryozoa are all that have been collected. Towards the upper limit of the group silicified wood is found in the Pegus. The boundary between the Pegu and Irrawadian of this tract is sometimes marked by numerous thin bands of lateritic conglomerate; in other places, for example south-west of Pyinmana, beds of Pegu facies appear to pass up gradually into Irrawadian sandstones without the intervention of any such red beds. Near Lewe a fresh-water fauna is recorded in the topmost Pegu beds which contain abundant specimens of large *Batissa* belonging to a new species related to *B. inflata* Prime, but very much larger, and with its valves in most cases united; in addition there is a doubtful *Velorita*, specimens of a small *Corbicula* and casts of a *Unio*.

Along the eastern borders of Insein the boundary between the Pegu and Irrawadian is described as not at all well defined, the uppermost Pegu appearing to pass gradually and conformably up into the younger series.[123]

Pegu inliers are seen in the hills west of the Rangoon-Mandalay railway line, in Yamethin, Meiktila, Kyaukse and Sagaing, forming an outlying fringe to the north-eastern part of the Pegu Yoma, and are interesting in that they show clearly an unconformity between the Pegu and the Irrawadian,[124] some of them have already been referred to.

The Arakan Coast.—A small island, known as Kaunran-gyi, on the Arakan coast, is composed of a very pale brown or cream-coloured, calcareous sandstones or earthy limestone, containing echinoderms, molluscs, sharks' teeth and other fossils. The same rock occurs also at Nga-tha-mu on the mainland opposite but has not been recognised elsewhere. The most abundant amongst the fossils are a species of *Echinodiscus* ("*Lobophora*") and an *Echinolampas* which appears to be *E. jacquemonti* (d'Arch. & H.) one of the commonest fossils of the Gaj series in Sind; the *Echinodiscus* also closely resembles a Gaj species. The bed, somewhat similar to the Miliolite of Kathiawar, may represent the upper portion of the Pegu; one of the sharks' teeth closely resembles one found in that series south of Thayetmyo.[125]

The Andaman Islands.—On Paget Island, one of the Andaman group, occur beds lying unconformably upon the Eocene and crowded with *Amphistegina niasi* Verb. and *Nummulites niasi* Verb., the latter closely resembling the European *N. budensis*.

In Java these foraminifera are said to occur at a higher horizon than the large lepidocyclines. The strata with *Nummulites niasi*

[123] Gen. Rep. Rec., 62, 115 (1929).
[124] Gen. Rep. Rec. 60, 85 (1927).
[125] Man., 2nd Edit., 340 (1893).

found in the Andamans as well as in Borneo are regarded by Douville as of Burdigalian age,[126] and thus equivalent to the Gaj; Cotter considers that the Andaman beds may be slightly older and suggests a Nari age (Aquitanian). The same rocks in Interview Island have yielded both the foraminifera mentioned above and in addition species of *Rotalia*, *Globigerina* and others, as well as small lepidocyclines perhaps referable to *Lepidocyclina sumatrensis*.[127]

PALAEOGEOGRAPHY IN OLIGOCENE-MIOCENE TIMES.

At the end of the Eocene the west Indian gulf shortened very considerably, retreating from the Himalayan region and northern Punjab until its head lay to the south of the Bugti hills. This extensive regression was, however, followed immediately by a renewed northward transgression but only as far as the Loralai area, the water in Lower Nari times creeping northwards over Eocene strata eroded in some places down to the Middle Kirthar. The sea communication with southern Europe must have been well maintained till the middle of the Oilgocene period, since the faunal resemblances between the two regions persisted and in fact increased during the Lower Oligocene. In Upper Oligocene times important changes seem to have taken place in western Asia. The gulf of western India receded and was replaced by an estuary which received the waters of the forerunner of the Lower Indus. By the rise of land in western Asia the Mediterranean as well as the Russo-Boreal waters became completely separated from the Indo-Pacific region which from that time began the development of the particular fauna that characterises it at the present day.

While the Alps of Europe in early Miocene times were rising out of the Tethys sea in a series of loop-like ridges, the Himalaya continued to soar upwards over the great river valley which had replaced the marine Eocene gulf. The Miocene fauna of the Indo-Pacific ocean, which is known in Zanzibar, Madagascar, northwest India, Ceylon, Burma, Java, the Celebes, New Guinea and Fiji, is much the same in aspect as the fauna of today. As Morley Davies remarks,[128] the only important absentees in modern times are the larger foraminifera, *Lepidocyclina* and *Miogypsina*, and the cephalopod, *Aturia*. The relations of the Mediterranean and Indo-Pacific oceans during the Miocene epoch have been recently summarised by Davies who notes that they are by no means clear. An increasing divergence between the faunas of these two basins from the Upper Eocene onwards becomes marked in Miocene times. Although identical or closely related species are equally common in both regions, the Indo-Pacific includes a number of genera and families which are either quite unknown in the contemporaneous Mediterranean assemblage, or make the abrupt appearance characteristic of migrant forms. There is, moreover, evidence of an imperfect land connection between Africa

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[126] Bull. Soc. geol. de France., 4th Ser. 5, 448 & 451 (1905).
[127] E. W. Vredenburg, Rec. 34, 93 (1906).
[128] "Tertiary Faunas" 175 (1934).

and Eurasia in Acquitanian times which had not been there during the Oligocene; this is suggested by certain affinities between the mammalian fauna of Ethiopia and that of the Bugti beds of Baluchistan. The position of this land bridge is not easy to discern, for the Miocene Mediterranean appears to have extended as far as Persia, covering large areas in Alegria and Tunis and part of northern Egypt. The Miocene faunas of Egypt, unquestionably Mediterranean as they are in the main, show evidence of sudden and temporary invasion of Indo-Pacific forms, probably via Arabia and Persia. In Persia the Miocene is represented by a basal 1,000 feet of limestone—the Asmari Limestone—which in many places carries rich supplies of petroleum, and a succeeding series of gypseferous and oil-bearing sediments, known as the Fars series and some 10,000 feet thick.

Even as early as Middle Miocene times, Pilgrim surmises that the Himalaya and adjacent ranges had attained a sufficient height to serve as a partial barrier to emigrations from central Asia.

The two gulfs on the east side of India became more and more widely separated from each other by the continued rise of the Arakan Yoma. The more westerly of these twin gulfs lay between the Shillong Plateau and the Yoma and was replaced by the Meghna valley; in this shallow gulf and valley were deposited the oil and coal of lower and upper Assam. The Burma gulf, between the Arakan Yoma and the Shah Plateau persisted, with two or three islands in the north, but there is evidence of a steady retreat southwards of the sea and of its replacement by fluviatile deposition. In this Pegu gulf took place the accumulation of the vegetable matter which under some conditions gave rise to coal and under others to oil. In the latter case the conditions seem to have been those of salinity. This formation of oil and coal had already commenced in the preceding Eocene period, not only in the Burmese gulf but also in the two Indian gulfs. In the Assam gulf more coal than oil appears to have been produced, in the West Indian gulf the accumulation of coal was on a comparatively small scale and the formation of oil was confined to the Eocene, so far as our konwledge goes, and took place for a restricted period only. Sea communication with Borneo and the Philippines was maintained round the broad Cathaysian promontory. The history of the rivers which replaced the gulfs is as yet little more than interesting surmise and will be alluded to in the final chapter.

CHAPTER XXXIII.

TERTIARY (CONTINUED)—THE UPPER MIOCENE AND PLIOCENE.

I. Western, Northwestern and Northern India: The Siwalik and Manchhar series: **The Manchhar series.** Sind and Baluchistan; Kathiwar. **The Makran series**; Sind and Baluchistan; Cutch; Kathiawar. The Siwaliks of Kalat State, Baluchistan. The Siwaliks of the Sibi-Pishin area. The Siwaliks of the Bugti and Marri hills. The Siwaliks of the Sulaiman Range; Afghanistan; Persia and Mesopotamia; Chitral; Waziristan; Bannu and Kohat. The Siwalik series of the Potwar Plateau: Subdivision; Continuity of deposition; "Pseudo-conglomerates"; Petrography of some of the Siwalik sediments and deductions therefrom; **The Lower Siwalik**—Kamlial stage—Chinji stage; **Middle Siwalik**—Nagri stage—Dhok Pathan stage; **The Upper Siwalik**—Tatrot stage—Pinjor stage—Boulder Conglomerate. Punch and Gujrat districts. Jammu and Gurdaspur—Pabbi hills. **The Siwalik Hills (Kangra, Hoshiarpur, Ambala, the Simla Hills states including Bilaspur, Dehra Dun, Garhwal, Naini Tal and Nepal)**: Distribution, mode of occurrence and structure; the Nahan group; Post-Nahan Siwaliks; Nurpur beds; Nagri stage; Dhok Pathan stage; Pinjor stage; Boulder Conglomerate. Garhwal and Kumaon. Nepal. Darjeeling. West Bhutan—East Bhutan. Aka Hills. Dafla Hills. Miri Hills. Abor Hills. Mishmi Hills. **The Mollusca, fishes, reptiles and birds of the Siwaliks. General considerations regarding the Siwalik fauna.** II. The Tipam Series of Assam: Distribution and subdivision; Tipam Sandstone; Girujan Clay stage; Num Rong Khu stage; Dihing stage; The Tipams in Chittagong; Karikal. III. The Irrawadian Series of Burma: Terminology; Stratigraphical limits; Distribution; Lithological character; Contrast to Pegu; Relationship to the Pegu Basal beds; Vertebrate remains; Invertebrate fauna; Vegetable remains; Thickness; The upper boundary; Northern exposures; The Jade Mines area of Myitkyina; Tenasserim.

I. Western Northwestern and Northern India.

The Siwalik and Manchhar series.—The youngest Tertiary group in north, northwest and western India is known as the Siwalik in the Himalaya, Punjab and North-west Frontier, and as the Manchhar in Sind and eastern Baluchistan. The two terms are regarded as synonymous, but the name Manchhar is retained because it has been so widely used. The Manchhars have been divided into two stages, a Lower and an Upper; along the Makran coastal region the place of the latter is believed to be taken by a marine or estuarine series known as the Makran series (see Table, p. 1639).

THE MANCHHAR SERIES.

Sind and Baluchistan.—The Manchhar beds of Sind are well developed and occupy a large plain opening northwards to the Indus and lying between the Laki range on the west and another belt of Eocene on the east separating it from the Indus river. Here the beds lie upon the Laki limestone, with the occasional intervention of a very meagre and imperfect representative of the Gaj; they also lie upon the Laki limestone in the case of a small exposure on the

Indus a few miles above Hyderabad. They reappear in many places in the different synclinal valleys to the west of the Laki range, where they are in contact, sometimes with the Laki Limestone, sometimes with the Upper Kirthar, sometimes with the Upper Nari, and sometimes with the Gaj. Further south over a large area the Lower Manchhars lie unconformably upon the Laki Limestone.[1] Throughout these areas in Lower Sind, the Manchhar rocks are not so well seen as they are to the north, the soft sandstones and clays of the group having been denuded into undulating plains and largely concealed beneath the pebbles and sands derived from the comparatively hard older Tertiary rocks of the neighbouring hills; it is, consequently far more difficult than in Upper Sind to distinguish the different portions of the series, or to form a correct idea of the thickness present. The Manchhars are seen west, south and east of the Manchhar Lake, after which they have been named; thence northwards they form a broad fringe to the Kirthar range along the edge of the Indus alluvium throughout Upper Sind to a point west of Shikarpur. The breadth of this outcrop varies greatly, being as much as 14 miles west of Larkana, but diminishing both to the north and south. The Manchhars attain their maximum thickness of little less than 10,000 feet where their outcrop is widest. This maximum breadth, however, is not due merely to their greater development. but also and principally to a synclinal and anticlinal roll which the beds form before disappearing beneath the alluvium; in other parts of the range the same beds are exposed in a simple section, all the strata dipping eastwards. To the north the section is complicated by faulting, but to the south the thickness of the Manchhar series diminishes greatly and, to the west of Sahwan, although both lower and upper subdivisions of the group are present, including the uppermost conglomerate, the total thickness of the beds cannot be much more than about 3,000 feet of which not less than 1,500 feet belong to the basal or Kamlial stage of the Siwaliks.[2] Throughout nearly the whole of this exposure the Manchhars are in contact with the Gaj. Farther north the beds are again seen, forming a fringe to the alluvium, narrow at first but broadening out to a wide re-entrant tract around and to the north of Sibi. Here more generally known under the name of Siwalik, the beds which are not so thick as they are in northern Sind, swing round in a crescentic fringe to the Bugti hills and have been traced up the western side of the Indus valley into Waziristan. Some obscure exposures of the Manchhar series have been recorded around Mastung and further west in the northern part of the Las Bela plain.

The Manchhar is essentially a fresh-water series made up largely of alternations of shale and sandstone but, unlike its equivalent the Siwalik, it has occasional estuarine horizons which indicate temporary reversions to brackish or salt-water conditions. Some of the Siwalik stages, especially the basal one, have been recognised in the

[1] W. L. F. Nuttall, Q. J. G. S. LXXXI, 419 (1925).

[2] G. E. Pilgrim, Rec. XXXVII, 161 (1908).

Manchhar exposures, and further fossil collecting will probably establish a more complete and detailed correlation. The original subdivision was into two portions, a Lower and Upper, between which it is difficult to draw an absolute line. To avoid confusion it is proposed to retain provisionally this two-fold division, but it will probably be found that, while the Lower Manchhars are the equivalent of the Lower Siwalik, the Upper Manchhars, when fully developed, represent both Middle and Upper division of the Siwalik series.[3]

In the northern part of Sind the Middle Siwalik is partially represented by the Lower portion of the Upper Manchhar, but is said to be absent in southern Sind where the series appears to be represented mainly by estuarine beds indistinguishable in facies from the Makran beds; of the fresh-water Manchhar facies there remain a meagre 200 feet or so of strata.[4]

The Lower Manchhar of Sind, or Lower Siwalik if we like to call it so, is composed mainly of a characteristic grey sandstone, rather soft, moderately fine in grain, and made up of quartz with some felspar and hornblende; in addition there are red sandstones, conglomeratic beds and, towards the base, red, brown and grey clays. The components of the conglomeratic beds are chiefly nodules of clay and soft sandstone, derived apparently from typical Siwalik beds; they never include, so far as is known, any fragments derived from the older Tertiary rocks such as the characteristic Gaj limestones or the still more easily recognised Kirthar limestone. These conglomeratic beds of the Lower Manchhar are frequently ossiferous, the bones and teeth, however, being usually isolated and fragmentary.

The Upper Manchhar subdivision, along the flanks of the Kirthar range west of Larkana, where it is best seen, is thicker than the Lower and differs therefrom in the great predominance of conglomerates. Towards the base it consists of a great thickness of orange or brown clays, with subordinate bands of sandstone and conglomerate. The sandstones are usually light brown in colour but are occasionally grey like the characteristic beds of the Lower subdivision. The higher portion of this Upper sub-group contains more sandstone and conglomerate, and the whole is capped by a thick band of masive, coarse conglomerate, which forms a conspicuous ridge along the edge of the Indus alluvium throughout Upper Sind. This conglomerate contains numerous large pebbles of Eocene and Gaj limestone, together with fragments of quartzite and other rocks of unknown origin. Throughout the Upper Manchhar conglomerates, the presence of pebbles of Eocene limestone and of the brown Gaj limestone, indicates that these older Tertiary rocks were undergoing denudation during the Upper Manchhar epoch; on the other hand, as already indicated, there is no such evidence of the erosion of these

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[3] Colbert equates the Lower Manchhar with the Lower and Middle Siwalik, and the Upper Manchhar with the Upper Siwalik (Trans. Amer. Phil. Soc., 26, 28 (1935).

[4] Gen. Rep. Rec. 47, 4 (1916).

beds in Lower Manchhar times. Nevertheless, that some disturbance of the older Tertiaries took place before the deposition of the Lower Manchhar sediments is proved by the absence of the Nari and Gaj between the Eocene and the Manchhar for long distances; for many miles, as we have seen the Kirthar too is not seen and the Manchhars lie directly upon the Laki limestone. That disturbance of the older Tertiaries took place before the deposition of the Lower Manchhar is well exemplified on the east side of the Laki range where Manchhar beds, including the Lower subdivision with mammalian teeth and bones, themselves disturbed, rest uncomformably on Kirthar strata which in many places are vertical.

In Upper Sind no marine or estuarine fossils have been observed in undoubted Manchhar beds, with the exception of some rolled oyster shells, found at the base of the Manchhars near the Nari stream, and derived from a lower formation; underneath are the estuarine passage beds which we have placed at the top of the Gaj (p. 1641).[5] In Lower Sind, there is a very considerable intercalation of marine or estuarine beds among the Manchhars, and this evidence of deposition in salt water increases in the neighbourhood of the present coast. Around Karachi beds of oysters, and sometimes of other marine or estuarine shells, are not infrequently found in the Manchhar series. In the direction of the coast there is also some change in mineral character, the sandstones becoming more argillaceous and associated in places with pale, grey, sandy clays and shales. The passage from the Gaj into these beds is very gradual, calcareous bands with Gaj fossils such as *Ostraea latimarginata* and *Pecten* (*Amussium*) *subcorneus* occurring some distance above the earliest appearance of the Manchhar type of sediment.[6]

Away from the coastal area there is every reason to believe that the Manchhar group is of fluviatile origin. Although there is no difficulty in drawing a line between Manchhar and Gaj beds, except in the neighbourhood of the coast, everything tends to show that there is no appreciable break in time between the two, the lower portion of the upper group being an estuarine or fluviatile continuation of the underlying marine beds. The great thickness of the Manchhar series in Upper Sind would alone suffice to prove that a considerable period of time must have elapsed during the deposition of this formation, and palaeontological evidence goes to show that this interval stretches from the Middle Miocene (Helvetian) to the end of the Pliocene and perhaps into the Pleistocene.

The two stages which form the Lower Siwalik have both been recognised in the Lower Manchhars. The basal stage, or Kamlial,

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[5] In the Gaj river section in Upper Sind, estuarine shells have been repirted by Vinayak Rao in Lower Manchhar beds (Gen. Rep. Rec. 47, 41 (1916).

[6] These particular beds were mapped as Makran ("Hinglaj") by Vredenburg (Rec. 38, Pl. 12 (1909).

has yielded the following vertebrate remains:[7]

CARNIVORA.

Amphicyon sindiensis Pilg.[8]

PROBOSCIDEA.

Dinotherium sindiense Lyd.,
Trilophodon angustidens, var. *palaeindicus* Lyd. (species in Europe and Africa ranging from Burdigalian to Sarmatian).

ARTIODACTYLA.

Conohyus sindiensis Lyd.,
Listriodon guptai Pilg. (cf. *L. lockharti* and *L. latidens* from the European Burdigalian and Vindobonian),
Hyoboops palaeindicus Lyd.,
Hemimeryx blanfordi Lyd.,
Microbunodon cf. *silistrensis* Pentl.,
Dorcabune sindiense Pilg.
Propalaeomeryx oxigna pilg.,
Propalaeochœrus (?) *lahirii* Pilg.[9].

Probably from the same stage and certainly from beds of Lower Siwalik age come the following additional forms.[10]

PISCES.

Arius (?) sp.

REPTILIA.

Crocodilus palaeindicus Falc.,
Garialis pachyrhyncus Lyd.,
Garialis curvirostris Lyd. (this and the two preceding are confined to this Sind fauna).

ARTIODACTYLA.

Chœromeryx sindiense Lyd.,
Palaeochœrus sindiensis Lyd.,
Brachyodus sp.[11]

PERISSODACTYLA.

Rhinoceros sivalensis Falc. & Cautl., var.,
Teleoceras blanfordi (Lyd.), var.[12]

PROBOSCIDEA.

Dinotherium indicum, var. *pentapotamiae* (Lyd.),
Chœrolophodon palaeindicus (Lyd.),
Mastodon (? *Trilophodon*) *latidens* Clift.

At a horizon some 500 to 600 feet higher, which is correlated with the Chinji stage, B. B. Gupta has collected:

PROBOSCIDEA.

Trilophodon macrognathus (Pilg).

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[7] G. E. Pilgrim Rec. 48, 100—101 (1917).
[8] Pal. Ind., New Ser., Vol. 23—24 (1932).
[9] Pal. Ind., New Ser., Vol. 8, No. 4, 47 (1926).
[10] Rec. 37, 161—163 (1908).
[11] G. E. Pilgrim Rec. 43, 317 (1913).
[12] G. E. Pilgrim Rec. 43, 317 (1913).

ARTIODACTYLA.

Hyotherium chinjiense Pilg.,
Listriodon pentapotamiae Lyd.,
L. theobaldi Lyd. (from the Lake Hills).,
Hemimeryx pusillus Lyd.,
Dorcabune anthracotheroides Pilg.,
Dorcatherium minus Lyd.,
Giraffokeryx chinjiensis Pilg.

Some 500 or 600 feet higher up, the following species occur within the Upper Manchhars and belong to the Dhok Pathan, one of the Middle Siwalik stages.

PERISSODACTYLA.

Hipparion punjabiensis Lyd.,
Rhinoceros sivalensis Lyd.

ARTIODACTYLA.

Pachyportax latidens (Lyd).

Probably about 4,000 or 5,000 feet of the Manchhar series belong to the Middle Siwalik in parts of Sind and Baluchistan.[13]

In addition to the above, the Manchhars of Sind have yielded the following, mostly if not entirely from the lowest 100 feet.[14]

PROBOSCIDEA.

Tetralophodon pandionis (Falc.) (Lower and Middle Siwalik form),
Pentalophodon falconeri (Lyd.),
Mastodon perimensis Falc. & Cautl. (a Lower Siwalik form).

PERISSODACTYLA.

Aceratherium perimense Falc. (a Lower Siwalik form),
Aceratherium gajense, var. *intermedium* Lyd. (a Lower Siwalik form).

ANCYLOPODA.

Nestoritherium (?) *sindiense* (Lyd.) (a Lower Siwalik, probably Chinji form genus probably a descendant of *Chalicotherium*).

ARTIODACTYLA.

Microbunodon (*Microselenodon*) *silistrense* Pentl. (a Lower Siwalik, — probably Chinji form),
Telmatodon (?) sp. Pilg. (a Lower Siwalik form),
Chaeromeryx silistrensis Pentl. (a lower Siwalik form),
Sus hysudricus Falc. & Cautl. (found in Lower, Middle and Upper Siwalik),
Dorcatherium majus Lyd. (found in the Lower and Middle Siwalik),
Progiraffa sp. Pilg. (a Lower Siwalik form).

Further comments on the Siwalik vertebrate fauna will be made in the sequel, but it may here be noted that, with the exception of *Hyoboops palaeindicus*, no form is without varietal differences when compared with the Bugti bone beds of Upper Gaj age. The few estuarine shells found in the lowest Manchhar beds in Upper Sind. and a portion at least of the marine fossils procured from a similar

[13] G. E. Pilgrim Rec. 37, 165 (1908).
[14] Rec. 40, 198-203 (1910); Rec. 43, 316—318 (1913).

horizon near Karachi, appear to be Gaj forms, and to indicate a close connection between the Lower Manchhars and the underlying group. In places, and especially in the neighbourhood of the Laki range, silicified fossil wood is found in abundance in the Manchhar beds, stems of large trees being of common occurrence; the majority are dicotyledonous but a few fragments of monocotyledons are also found.

Kathiawar.—The uppermost of the Kathiawar Tertiaries are sandstones and conglomerates, the best known exposure of which is seen in the tiny island of Piram or Perim[15] a reef only 1,800 yards long by 300-500 yards broad, which achieved geological celebrity by the discovery therein of fossil mammalian bones in 1836. The bones are found in the conglomerate bands, most of them in such a band which lies considerably below high-water level and is obscured by a thick covering of mud for the greater part of the year. During the months of April, May and June, however, the southeast end of the reef becomes scoured and free of mud, and fossil bones are obtainable; of these the first collectors reaped a rich harvest in the accumulations of ages. At one time provisionally referred to the Nagri stage of the Middle Siwalik[16] these beds are now definitely regarded by Pilgrim as the equivalent of the Dhok Pathan, on account of the occurrence in them of the large giraffoid, *Brahmatherium perimense* and the large *antelopes, Tragocerus perimensis, Selenoportax lydekkeri* and *Perimia falconeri.*[17] The following additional determinations have been made:

REPTILIA.

Corcodilus palaeindicus Falc.,
Garialis gangeticus (Gmel.).

PROBOSCIDEA.

Mastodon (Trilophodon) pandionis Falc.,
Mastodon (Tetralophodon) perimense Falc. (cf. M. (*T.*) *longirostris* from Eppelsheim),
Mastodon (Stegolophodon) cautleyi (Lyd.),
Mastodon (Chœrolophodon) corrugatus (Pilg.).

PERISSODACTYLA.

Aceratherium perimense Falc.,
Hipparion punjabiense Lyd.,
Hipparion perimense Pilg.,
Hipparion feddeni Lyd.

ARTIODACTYLA.

Merycopotamus cf. *dissimilis* Falc.,
Palaeochœrus (?) *perimensis* Lyd. (a survival from the Oligocene),
Propotamochaerus cf. *uliginosus* Pilg.,

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[15] Piram is the more correct spelling but the form "Perim", has become of classic importance and has lent its name to more than one fossil species; it must not be confused with the larger island in the Straits of Bab-eit-Mandeb

[16] Rec. 43, 320—321 (1913).

[17] G. E. Pilgrim, Pal. Ind., New Ser., Vol. 18, 6 (1932).

Palaeochoerus cf. *salinus* Pilg.,
Giraffa sp. Falc.,
Bramatherium perimense Falc.,
Tragocerus perimensis (Lyd.),
Selenoportax lydekkeri Pilg.,
Perimia falconeri (Lyd.),
Cambayella watsoni Pilg.,
Gazelline genus (cf. *Antilope*) *planicornis* Pilg.

THE MAKRAN SERIES.

Sind and Baluchistan.—Wherever the Manchhar type of sedimentation occurs in Sind, the newest beds below it are what have been alluded to above as the transition beds at the top of the Gaj. This is now to be described as a marine or estuarine series, corresponding to the Upper Manchhar, and displayed to the west of Sommiani Bay, near Hinglaj. This is a marly series, known as the Makran,[18] which is from 3,000 to 4,000 feet thick in the Hinglaj mountains and passes down into the shaly series of the Kojak Shales, the upper portion of which must represent both the Gaj and Lower Manchhar. The Makran series never comes into contact with the Manchhar beds, and there is no resemblance between the two formations, the one being marine or estuarine and the other fluviatile. Corresponding to the Pliocene and perhaps lowest Pleistocene (Villafranchian) of the European sequence, the Makran series, so called by Blanford from the name of the littoral tracts of Baluchistan,[19] consists essentially of thick beds of pale grey clay, more or less indurated, with occasional bands of shelly limestone, calcareous grit and sandstone.

The Makran series, covering a large area in the eastern, south-eastern and southern portions of Kalat State, Baluchistan, extends for many hundreds of miles along or close to the coast of Baluchistan and Persia and is well exposed, not only in the Hinglaj mountains and the Talar-i-Band or Makran Coast Range, but also in the headlands of Ras Malan, Ormara and Gwadar, the last not far from the Persian frontier. These headlands are portions of great horizontal plateaux, one of them, Ras Malan, being nearly 2,000 feet above the sea; they are surrounded by cliffs of whitish marl of clay and capped by dark coloured calcareous grit. In all the sea cliffs this clay is well exposed and rapidly disintegrates; the prevalent rock along the Makran coast, is a pale grey clay, more or less indurated, usually sandy and often highly calcareous, occurring in beds of great thickness and occasionally seamed with veins of gypsum. With this clay or marl are interstratified bands of shelly limestone, dark calcareous grit and sandstone, but these form a small proportion of the total mass, although their greater hardness makes them conspicuous at the surface. It is on the surface of rocks belonging to this series that the previously mentioned mud volcanoes occur.[20]

[18] The term Makran (Mekran) has been used in a more extensive sense, embracing the Nari, Gaj, and Hinglaj; it is now restricted to the last, with which it becomes synonymous.

[19] Rec. 5, 43 (1872).

[20] W. A. K. Christie. Rec. 42, 279—280 (1912).

The Makran is shallow-water marine or estuarine series, abounding in molluscs and echinoids, the majority of the species being found still living in neighbourhood areas. The lower beds contain many of the typical Gaj mollusca, but only one doubtful echinoid is common to the two formations. The peculiar *Ostraea angulata* and *O. latimarginata* of the Gaj are, however, not found in the Makran beds. One of the most characteristic fossils of the Makran beds is *Ostraea* (*Alectryonia*) *virleti* Desh., an abundant form in the Middle Fars of Persia. This oyster, found typically in the Lower Makran or Talar stage but occurring as well in the upper or Gwadar stage[21] has a wide range in time and space; Professor Morley Davies notes that it is known in Spain and Portugal, Cyrenaica and Egypt, Thrace and Morea, Armenia and Persia, Burma and east Africa, while allied species have been found in the West Indies and California, the combined range extending from Lower Miocene to Middle Pliocene, with perhaps a maximum development in the Middle Miocene.[22] Associated with it in the Makran beds are close-ribbed forms referable to *O. digitata* Eichw., var. *rholfsi* Fuchs (*O. digitalina* auctt. *rholfsii* Fuchs, and *O. promensis* Noetl.);[23] this form Davies records as being present in the Middle Miocene of Volkynia, Persia, India, Burma and Java.[24] The uppermost sandstone beds of the series in some of the Persian Gulf islands contain an echinoid fauna different from that of the Gaj, while the Indian equivalents are characterised by a rich assemblage of Pectens, of which the most conspicuous is *Pecten vesseli* Fuchs, a common and trustworthy index fossil in the Upper Fars of Persia, exposed in most of the Persian Gulf islands, and the leading form of the Kabret plateau fauna in the Isthmus of Suez. In the Makran fauna *Operculina* is the common foraminiferal genus, and gastropods are less common than lamellibranchs; the following is a list of known forms.[25]

(Ta.=Lower or Talar stage. Gw.=Upper or Gwadar stage).

ECHINOIDEA.

Salmacis sp.,
Temnopleurus simplex Dunc. & Sl.,
Clypeaster suffarcinatus Dunc. & Sl.,
Laganum tumidum Dunc. & Sl.,
Echinodiscus auritus Leske, var.,
Schizaster sp.,
Breynia ? sp. (young).

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[21] E. Vredenburg, Mem. 50, 426—427 (1928); G. E. Pilgrim Mem. 34, pt. 4, 27, 31 (1908).

[22] "Tertiary Faunas", Vol. 2, 160—161 (1934).

[23] A Morley Davies, "Tertiary Faunas", Vol. 2, p. 160 (1934); E. Vredenburg, Rec. 36, 320 (1907).

[24] The varietal distinction is not admitted by Professor J. A. Douglas, who refers to this form simply as *Ostraea digitata* Eichw. (Contributions to Persian Palæontology. Oxford; The Holywell Press; published by the Anglo-Iranian Oil Co. (1937).

[25] P. M. Duncan and W. P. Sladen, Pal. Ind. Ser. 7 and 14, pt. 3 fasc., 6 (1886); E. Vredenburg, Mem. 50 (1925—1928).

LAMELLIBRANCHIATA.

Arca inflata Reeve (Ta. and Gw.) (living in the Arabian Sea),
Arca clathrata Reeve var. *burnesi* d'Arch. (basal Ta.; also found in the Gaj),
Arca tambacana Mart. (Gw.),
Arca rhombea Born. (Ta),
Arca nannodes Mart. (*basal* Ta; also in the Miocene of Burma),
Arca bataviana Mart. (Ta.; Miocene of Burma),
Arca squamosa Lam. (G.w),
Arca divaricata Sow., (Gw.),
Arca decussata Sow., (Gw.),
Arca decussata Sow., (basal Ta.),
Arca newtoni Vred. (Ta.),
Arca mekranica Vred. (Ta.),
Arca tortuosa Linn. (Gw.),
Glycimeris (Pectunculus) gwadarensis Vred. (Gw.),
Placuna (Indoplacuna) iranica Vred.,
Ostraea pseudorissensis Vred. (Gw.),
Ostraea digitata (digitalina) Eichw., var. *rholfsi* Fuchs (basal Ta; found also in the Pegu of Burma),
Ostraea pseudodigitalina Fuchs (Ta.),
Ostraea (Alectryonia) virleti Desh. (basal Ta. and Gw.),
Ostraea petrosa Fuchs (basal Ta.),
Ostraea forndosa de Serres (Gw.)
Ostraea gingensis (Schloth). (Ta.),
Ostraea pseudocrassissima Fuchs. (Gw.),
Ostraea bicolor Hanley (Gw.),
Ostraea crenulifera Sow. (Gw.),
Ostraea cucullata Born. (Gw.),
Ostraea parasitica (Gmel.) (Gw.),
Chlamys prototranquebaricus, var. *paucicostatus* Vred. (Gw).
Chlamys alexandri Vred. (especially Gw.),
Chlamys vasseli Finchy (especially Gw.),
Chlamys nearchi Vred. (Gw.),
Cardium (Discors) triforme Sow. (basal Ta.),
Cardium (Laevicardium) melvilli Newton (Gw.),
Cardium (Laevicardium) unicolor Sow., var. (Ta.),
Dosinia pseudoargus (d'Arch. & H.) (basal Ta.),
Dosinia pseudoargus (d'Arch. & H.), var. *gedrosiana* Vred. (Gw.),
Dosinia subpenicillata Vred. (basal Ta.; very close to the living *D. penicillata* Reeve),
Dosinia peralta Vred. (basal Ta.),
Cytherea (Callista) florida (Lam.),
Cytherae (Callista) pseudoumbonella Vred. (basal Ta. and Gw.; found also at Jaskh),
Venus (Omphaloclathrum) mekranica Vred. (basal Ta.),
Venus (Clementia) papyracea Gray (basal Ta. and Gw.),
Venus (Clementia) papyracea Gray var. *grandis* Vred (Gw.),
Circe corrugata (Chemn.), (Gw.; found also at Jaskh),
Tapes (Callistotapes) pseudoliratus Vred. (basal Ta.),
Tapes (Textrix) malabaricus (Gw.; also found near Jaskh),
Semele makranica Vred. (Basal Ta.),
Corbula mekranica Vred. (basal Ta.),
Corbula mekranica Vred. (basal Ta.).

GASTROPODA.

Terebra mekranica Vred. (Ta.),
Terebra gedrosiana Vred. (Ta; close to *T. mekranica*),
Terebra (Myurella) aspera Hinds (Ta.; living),

Terebra (Myurella) trizonata Vred. (close to *T. protomyuros* Noetl. from the Burma Pegu),
Clavatula sacerdos (Reeve) Gw.; (living off South and West Africa),
Clavatula (Perrona) unisulcata Cossm. (very close to *Cl. taxus* (Chemn.) from the Cape of Good Hope),
Clavatula (Clionella) sinuata (Born), var. *arabica* Vred. (species living in S. Africa),
Surcula tuberculata (Gray) (Ta. abundant; living),
Surcula fulminata (Kien.) (Gw.),[26]
Pleurotoma haydeni Vred. (Gw.),
Pleurotoma (Gemmula) congener E. A. Smith, var. *mekranica* Vred. (living in the Bay of Bengal and the Arabian Sea at depths of 120-400 fathoms; the equivalent of Martin's *Pl. coronifera* from the Miocene of Java),
Drillia (Crassispira) mekranica Vred. (Ta.),
Bathytoma cataphracta (Brocchi), var. *qedrosiana* Vred. (Ta.; species found in Europe and Burma; one of the few forms which, with slight modifications, travelled thus far east in Miocene times, genus still living in the Indian Ocean off Travancore),
Conus (Leptoconus) vimineus Reeve (Ta.; also in the Pegu of Burma),
Conus (Leptoconus) amadis Martini (abundant at various horizons; living in Indian seas),
Conus (Leptoconus) scalaris Mart. (Ta. from Java),
Conus (Lithoconus) djarianensis Mart. (at several horizons; found in Java; very close to *C. odengensis* Mart.),
Conus (Dendroconus) loroisii Kien. (highest Ta.; found in Java; a Recent. from very close to *C. berghausi* Mich.),
Trigonostoma crispatum Sow. (basal Ta.; A Recent species),
Oliva (Neocylindrus) mustelina Lam. (basal Ta.; living very close to *O. rufula* Ducl., another living form),
Athleta (Volutospina) mekranica Vred. (basal Ta.; the youngest species of this genus and very close to *A. sindiensis*),
Mitra inquinata Reeve (basal Ta.; living),
Mitra (Cancilla) flammea Quoy (basal Ta.; found also in Java and Karikal; living in all parts of eastern seas),
Clavilithes verbeeki Mart. (basal Ta.; found in Java; very close to *Cl. seminudus* which is abundant in the Pegu of Burma; genus still living off Java),
Lathyrus duplicatus Vred. (basal Ta.),
Turbinella mekranica Vred. (abundant),
Melongena (Pugilina) ponderosa Mart. (basal Ta.; one of the commonest fossils low in the Makran series; very close to *M. praeponderosa* (Noetl.) from the Pegu of Burma),
Siphonalia (Kelletia) mekranica Vred. (basal Ta.; very close to *S. nodulosa* Sok),
Tritonidea (Cantharus) erythrostoma (Reeve) basal Ta.),
Latrunculus (Eburna) spiratus Linn. (highest Ta.; Upper Miocene to Pliocene of Java, Sumatra and Kariwal),
Nassa (Telasco) mekranica Vred. (very close to the living *N. arcularia* (Linn.),
Murex (Acupurpura) troscheli Lischke,
Rapana bulbosa (Sol.) (living and common along the coasts of India),
Purpura (Stramonita) angulata Duj. (basal Ta; a European form).
Purpura (Thalassa) mekranica Vred.,
Cymia sacellum (Chemn.) (living and abundant on the coast of Java),
Cymia sacellum (Chemn.) var. *burrowsi* Newt.,
Hindsia mekranica Vred. (basal Ta.),
Hindsia ? varicifera A. Adams.,
Ranella bitucervularis Lam. (basal Ta.),
Ranella (Apollon) elegans Beck (living on Indian coasts),

[26] E. Vredenburg, Rec. 53, 86 (1921).

Ranella (Bufonaria) spinosa Lam. (highest Ta.; living form),
Cassidea (Semicassis)mekranica Vred. (basal Ta.),
Cassidea (Semicassis) ormarensis Vred.,
Dolium variegatum Lam. (living in Australia and off Muscat),
Dolium maculatum (Lam.) Desh. (found in the post-Tertiary of Pulicat Lake; perhaps identical with *D. modjokasriense* Mart. from the Upper Tertiary of Java),
Dolium losariense Mart., var. *mekranica* Vred. (species in Java),
Dolium (Eudolium) tessellatum Brug.
Dolium (Eudolium) ormarense Vred.,
Dolium (Eudolium) ? arabicum Vred.,
Pyrula ficus (Linn.) (basal Ta.; also in beds of the same age in Ramri Island; Pliocene or Upper Miocene of Java; a living form),
Pyrula menengtengana Mart. (found also in Java),
Strombus mekranicus Vred. (basal Ta.),
Rostellaria curta Sow. (Ta., living in neighbouring seas),
Cerithium (Vertagus) bonneti Cossm. (Ww.; found also at Karikal; very close to the Java forms, *V. gendinganense* Mart. *and V. jampangtengahense* Mart.),
Terebralia miosulcata Vred. (basal Ta.; very close to the living *T. sulcata* Born.),
Terebralia dimorpha Vred. (Ta.),
Terebralia sublignitarum Vred (basal Ta.),
Terebralia mekranica Vred. (Ta.),
Potamides (Cerithidea) jenkinsi Mart.? (basal Ta.),
Potamides (Cerithidea) fluviatilis Pot. & Michaud or *djadjariensis* Mart.,
Batillaria mekranica Vred. (Ta.),
Rimella (Dientomochilus) javana Mart., var. *gedrosiana* Vred. (species common in the Miocene of Java and the Philippines),
Cerithiopsis mekranica Vred.,
Turritella bandongensis Mart. (Gw; also in Java),
Turritella assimilis Sow. (basal Ta.),
Turritella (Torculoidella) angulata Sow., (Ta.; also in the Pegu of Burma),
Turritella bantamensis Mart. (Gw.),
Turritella subulata Mart. (basal Ta.; also in Java),
Turritella vitulata Ad. & Reeve (Gw.),
Solarium perspectivum Linn. (Ta.),
Crepidula (Siphopatella) subcentralis Cossm. (Gw.); found also at Karikal),
Natica globosa (Chemn.) (Miocene of Java; a common species living in the Indian seas),
Sigaretus protoneritoideus Vred. (Ta),
Xenophora (Tugurium) mekranensis Newton (Gw.).

CEPHALOPODA.

Nautilus pompilius Linn ? (Ta.; a living form).

Of the Makran fauna, that portion belonging to the lower or Talar stage corresponds to that of the Odeng beds of Java, which Martin equates approximately with the European Pontian. The most characteristic species of the Odeng beds, *Melongena ponderosa*, is found in abundance in the Talar stage. The proportion of living species among the Odeng Gastropoda is about 42 per cent.[27] and that in the Talar beds is not far short of the same figure.[28] The overlying Gwadar stage must correspond approximately with the Sonde stage of Java, perhaps encroaching to a slight extent into younger horizons. It contains something like 60 per cent. of living species, a fact which agrees

[27] Samml. des. geol. Reichs-mus. in Leiden; Ser. 1, Vol. 6, 161 (1900).
[28] E. Vredenburg, Rec. 51, 323 (1920).

well with an *Astian-Villafranchian* age. While the connection of the Makran fauna with the Java equivalent is close and striking, that with the European faunas has almost entirely ceased, and the two regions had, apparently, become severed from each other as completely as they are today. The Makran fauna, and especially that of the Gwadar stage, has many species in common with a rich Pliocene assemblage found at Karikal on the Coromandel coast[29] (see p. 1744).

Cutch.—The Manchhar or Makran beds appear to be widely developed in the main island of Cutch, where they form a broad arcuate fringe to the south of the older rocks. In the west they lie upon the "Argillaceous group" (Gaj), but eastwards they come in contact with the "Sub-Nummulitic group" the Deccan Trap and finally the Jurassic. Although covering a large area the beds are ill seen since they are much concealed by alluvial deposits. The principal members comprise a basal conglomerate, more or less ferruginous, followed in ascending order by thick brown sands and obliquely laminated nodular, calcareous and sandy clays. As in southern Sind, marine beds with large oysters are intercalated, and the succession would thus appear to have a Makran rather than a Manchhar facies. It is thought that this upper Tertiary group in the west may pass down into the representative of the Gaj which, to the eastward seems to have been denuded away before the deposition of the former.

Kathiawar.—In Kathiawar part of the beds mapped by Fedden as Gaj, especially those along the southeast of the peninsula, may belong to the Makran. In this southeastern area there are no good sections; locally fossils are plentiful and include the echinoid, *Coelopleurus forbesi* d'Arch. & H., but the highly fossiliferous Gaj beds of western Kathiawar have no place here.[30] Some of the Tertiaries in eastern Kathiawar, though mapped as Gaj, may even belong to the Manchhar series, as do those of Piram (Perim) Island, which were also mapped as Gaj but are undoubtedly the equivalent of the Dhok Pathan stage of the Siwalik (Pontian).[31] Nevertheless, from the eastern shore of Kathiawar opposite Piram, H. C. Das Gupta has collected fish teeth identified as *Hemipristis serra* Agass., a form found in both the Miocene and Pliocene and occurring in the Pegu of Burma, *Carcharias* (*Prionodon*) *egertoni* Agass., also found in the Burma Pegu, and a new species *Oxyrhina feddeni* Das-G.; the age indicated is Miocene rather than Pliocene, but the evidence is not conclusive.

Two or three of the Tertiary occurrences south and southwest of Bhawanagar may be of Makran or Manchhar age. In the northwest portion of the peninsula the fossiliferous Gaj beds are overlain by what have been described as the Dwarka beds.[32] The latter consists of soft, yellow, earthy or marly clays, gypseous in part, followed above by more or less marly or arenaceous limestones, which are generally soft and porous and largely made up of foraminifera cemented by

[29] E. Vredenburg., Mem. 50, 5 (1925).
[30] F. Fedden, Mem. 21, 108 (1884).
[31] G. E. Pilgrim, Pal. Ind., New Ser., Vol. 18, 6 (1932).
[32] F. Fedden, Mem. 21, 123 (1884).

calcite or of comminuted shells and corals. No determinable fossils have been found in these beds, whose relationship to the underlying fossiliferous Miocene or Gaj is probably one of conformity in spite of the sudden change in lithological character.

The Siwaliks of Kalat State, Baluchistan.—In the northern half of Kalat State, Siwalik outcrops of some considerable width form low insignificant hill ranges on both the north and south sides of the Siahan range which lies to the north of the Central Makran range. These beds, whose exposure extends westwards into eastern Persia, resemble the Siwaliks of the Pishin and Quetta area, and consist of conglomerates, not unlike those of recent times, friable sandstones, and clays; the last mentioned rocks, which are frequently white or brightly coloured in various tints of pale terra-cotta, ochre or green, often contain crystals of calcite and gypsum.[33] No fossils have yet been recorded from these beds.

Further north, Siwalik or "Gobi" deposits have been mapped by Vredenburg along the southern, and to a less extent along the northern edge of the sandy desert in Kharan and Chagai. Where they border the mountain ranges the beds are tilted at high angles and affected by thrusting; elsewhere they exhibit only slight and local warping. These strata consist principally of alternating pink and greenish clays, and occasionally sandstones and conglomerates: coarse conglomerates are especially characteristic of the uppermost horizons.

It is as veins and impregnations in rocks regarded as Siwalik clays that the sulphur of the Sanni mines occurs, in the Kachhi district of the Kalat State. The reserves were estimated by Cotter in 1919 to be 36,000 tons of sulphur rock or over 10,000 tons of sulphur.[34] From the plain rises a steep scarp of pink and buff Siwalik sandstone, with veins of selenite, a few bands of clay ironstone and a sandy limestone with nummulites, probably derived.

The Siwaliks of the Sibi-Pishin area.—Further northeast, in the country between Sibi and Quetta, the Siwaliks rest on the Spintangi Limestone. Griesbach gives the following succession which he divides into two groups separated from each other probably by an unconformity, the lower group consisting of three stages, (*a*), (*b*) and (*c*), and the upper of two stages, (*d*) and (*e*).[35]

	feet.
(*e*) Buff and grey sandstone, with shales and gypsum in veins and flakes	3,000-5,000
(*d*) Grits, and variously coloured clays and shales with gypsum	1,500
(*c*) Brick-red and reddish purple sandstones and shales the sandstones often mottled	1,500-2,000
(*b*) Pepper-and-salt sandstones with shales and towards the base, calcareous grits	700-800
(*a*) Grits with rolled nummulites often in regular layers, ferruginous breccia, and conglomerate of chert nodules	50-100

[33] E. Vredenburg, Mem. 31, 205 (1901).
[34] G. de P. Cotter, Rec. 50, 137 (1919).
[35] Rec. 26, 124 (1898).

There is everywhere a general parallelism of stratification between the Spintangi and the Siwalik and a superfical appearance of conformity, but on a close examination it is to be seen that there are slight though distinct traces of erosion at the contact, that pebbles of nummulitic limestone are found in the Siwaliks near their base, and that there is a progressive thinning out of the nummulitic limestone from east to west by removal of the upper beds. A distinct overlap can be traced in sections south of Nasak and Harnai, and the contrast is very marked between the deep brown, often weathered, ferruginous grit of the basal Siwalik and the light coloured limestones and sandstones forming the top of the Eocene. The stratigraphical gap between the two is of course a large one.

The bottom bed is never much more than 100 or 200 feet thick, except when traced eastwards to Tung, where it has thickened to 500 feet; beyond Tung it thins out and in the vicinity of Khattan dies out and is overlapped by the succeeding pepper-and-salt sandstones and red earthy clays.[36] The basal layer is nearly always the above mentioned grit with a few strings of pebbles or thin bands of conglomerate; when not replaced by ochreous deposits, the grit is commonly of a grey or greenish colour. Associated with this basal bed occurs locally chert conglomerate, almost entirely made up of chert nodules, often of very large size and cemented by a ferruginous matrix; some of these nodules may be derived from Upper Cretaceous or older Eocene (Lower Nummulitic) limestones but Griesbach thinks the greater number of them came from younger Eocene (Upper Nummulitic) beds which at Sukkur and other places contain great quantities of chert concretions with well preserved foraminifera.

With the exception of the basal bed, the succession shows the typical increase in general average coarseness from base to summit usual in the Siwalik sequence. Near the base the series is essentially argillaceous, the prevailing rock being a red or brown earthly clay. Upwards, interbedded sandstones become more and more frequent till they predominate; in them pebbles appear and gradually increase in abundance and size, until the uppermost beds are composed almost entirely of a great thickness of coarse conglomerates. The latter are said to graduate up into beds of Pleistocene age.[37] Near Quetta a *Melania* has been recorded from an horizon near the base of the series, but in too poor a state of preservation for specific identification.[38] Bones are found throughout, but are more plentiful in the lower horizons.

Near Quetta the thickness of the whole Siwalik series cannot be far short of 10,000 feet, of which only the smaller portion probably belongs to the Upper Siwalik; much of the succession, probably 4,000 or 5,000 feet, must belong to the Middle Siwalik.

[36] R. D. Oldham, Rec. 23, 99 (1890).
[37] R. D. Oldham, Rec. 25, 36 (1892).
[38] G. E. Pilgrim, Rec. 37, 161 (1908).

To the east and northeast of Quetta, irregular outcrops of Siwaliks of varying size are seen resting on the Dunghan Limestone or on various members of the Mesozoic. A broad Siwalik tract, carrying the town of Pishin, narrows E.N.E.'wards and after an interruption by the Spintangi Limestone continues eastwards past Hindubagh; after another interruption by the Kojak Shales it curves north-eastwards and has been traced as far as a point west of Fort Sandeman. The latter outlier owes its preservation to the faults which on both sides have let it down among older rocks; its sediments are said to have the general facies of the Nagri and Dhok Pathan stages.[39]

The Siwaliks of the Bugti and Marri hills.—In the Bugti and Marri hills the Siwaliks resemble the Manchhars, and can be separated into two main divisions which correspond approximately to the Lower and Upper Siwaliks, of the Punjab, the Middle Siwaliks being absent or doubtfully represented. As the higher beds often succeed the lower without any unconformity of dip, it is sometimes difficult to draw the upper limit of the latter, which are generally from 1,000 to 1,500 feet thick and rest with no visible discordance upon the bone beds of Gaj age or upon the Kirthar limestone. As in the Manchhar series of Sind, the most significant distinction between the upper and lower beds is the almost invariable absence of nummulitic limestone pebbles from the conglomerates of the latter in contrast to their presence in the younger part of the series.

The Lower Siwaliks of these hills, like the thin basal beds in the Sibi-Quetta area, are characterised by red or grey clays, intercalated with which are soft, grey, brittle, well-bedded sandstones. Amongst the sandstones occur very frequently scarp-forming, bone-containing conglomerates, which are described by Pilgrim as largely concretionary and made up of pellets of red clay and calcareous matter with occasional small ferruginous nodules in a sandy matrix of a different colour. The rolled clay pellets of this rock may perhaps have been derived from the red clays by contemporaneous erosion; pebbles of hard sandstone are not common. Such beds invariably occur at the base of the Lower Siwaliks in Sind and Baluchistan and are always ossiferous, though the fossils are generally badly preserved. Above the basal clays comes a "pseudo-conglomerate"—a massive sandstone in which calcareous segregation has taken place to such an extent and in such a manner as to give a conglomeratic appearance to the rock. These concretions, sometimes several feet across, are often of a red colour and show up the more conspicuously in the lighter coloured matrix. The pseudo-conglomerate weathers in a characteristically columnar and nodular fashion.[40] In some places the calcareous matter is so abundant as to produce an arenaceous limestone. Above the pseudo-conglomerate follows a varying thickness of characteristic fine-textured, grey sandstone containing numerous black grains of hornblende, with no trace of a pebble; they are distinguished from the Gaj sandstones by their much finer texture,

[39] Gen. Rep. 73, 82 (1938).
[40] G. E. Pilgrim, Rec. 37, 160 (1908).

their freedom from quartz pebbles, and by the absence of ferruginous matter.

In the Marri country the Lower Siwaliks—pseudo-conglomerates as well as sandstones and clays—are characterised by a red colour, and lie with no apparent discordance upon the Gaj bone beds or, where these are absent 22 miles west of Kumbhi and Gandoi, on the Kirthar. In the Gujru outlier and in other places between Gandahari hill and the Sham plateau, the Lower division is absent and the boulder bed at the base of the Upper Siwaliks lies unconformably upon the Gaj beds which are here very thick; further north, at Pishini, there cannot be more than 100 feet of the Lower Siwaliks between the Gaj and the Upper Siwaliks. Deposition seems to have ceased during Lower Siwalik times over parts of this region which may have formed high ground at the time, an idea which is supported by the greater disturbance of the beds.

The basal concretionary conglomerates contain vertebrate remains, which are always fragmentary and isolated and consist chiefly of crocodiles, chelonians, proboscideans and rhinocerotids; among them are: *Tetrabelodon angustidens*, var. *palaeindicus* Lyd., *Tetralophodon falconeri* Lyd., *T. pandionis* Falc. and *Dinotherium indicum*, var. *pentapotamiae* Lyd.

The Middle Siwaliks appear to be absent in the Bugti and Marri hills. Between Gandoi and Jacobabad the Upper Siwaliks are well developed and dip generally with apparent conformity to the Lower Siwaliks. North of Kalakhu, however, some 500 feet of these beds are seen resting on the upturned edges of the Lower Siwaliks, while in the Gujru and Sham area they overlie in many places the Gaj sandstones or the Kirthars either directly or with an intervening trace of the Lower Siwaliks. As Pilgrim remarks, there must be a very considerable unconformity and time-break between the Lower and Upper Siwaliks of this area, represented in Sind and in other parts of Baluchistan by 4,000 or 5,000 feet of Middle Siwalik strata.

The Upper Siwaliks, which are quite unfossiliferous, include a great thickness of boulder beds with limestone fragments larger than a man's head; these coarse deposits are well developed on the northern edge of the Sihaf plain, in the Kahan plain and elsewhere, the boulder debris often concealing all other formations. Brown sandstones and sandy clays are also very characteristic beds in this division. In the Bugti country the Upper Siwaliks rarely exceed 500 feet in thickness, but in the Marri hills they attain 2,000 feet or more.

The Siwaliks of the Sulaiman Range.—The Siwaliks along the eastern flank of the Sulaiman range resemble in general character those in Sind and Baluchistan on the one side and those in the northern Punjab on the other. In the southerly part of the range the total thickness has been estimated at 7,500 feet, of which 5,000 feet belong to the Lower and 2,500 feet to the Upper division. Between Fort Munro and Drug, Nuttall's estimate of the total thickness of the Siwaliks is about 10,000 feet; this includes the Lower

division, of sandstones and shales, and the Upper, mainly of conglomerates, but not the Middle which appears to be absent ;[41] the Lower Siwaliks of this section (Dera Ghazi Khan) have yielded *Dinotherium indicum* Falc.[42] In the more northerly parts of the range, known as the Shirani hills, the Lower Siwaliks become reduced to 2,000 feet in the Toi and Shingao valleys, and in the Lohara and Zao sections further north are absent altogether, a result due either to irregularities in original deposition, or to overlap by the Upper division, or to both.[43]

Afghanistan.—A large tract of Upper Tertiary beds extends northwards from the Safed Koh in Afghanistan, on the east side of Kabul, towards Jalalabad, and is seen again to the north of that town. Another patch has been mapped to the north of Kabul. The strata consist of the usual soft, pepper-and-salt sandstones, flaggy siltstones and conglomerates, having a strong resemblance to the Manchhars or Siwaliks of the Indus basin. They are said to be quite distinct from some later conglomerates and sands which rest discordantly upon them and are presumably of later Pleistocene age.[44]

These Siwalik beds are seen at intervals all over the area between Kabul and the Khyber.[45] All the great river valleys of eastern Afghanistan are filled with beds of sand-rock and conglomerate which are exactly similar to the Siwalik deposits and, like them, have undergone much folding and tilting. At Khurd Kabul the marl and carbonaceous clay underlying the upper conglomerates contain a few poorly preserved plant remains and fragments of a small *Planorbis*. Similar carbonaceous beds also occur east of the Lataband. On either side of the gorge of the Kabul river above Gogomanda, Siwalik beds are seen capping the cliffs 1,000 feet or more above the present river bed, whilst in the neighbourhood of Jagallak their dip is almost vertical where they abut against the older crystalline rocks. Out in the more open plains they are often quite horizontal. No actual palæontological evidence of the Siwalik age of these beds has as yet been recorded.

In Madar and Kahmard, beds which Hayden suggests may be Eocene are unconformably overlain by red conglomerates and pebbly sandstones, very suggestive of the Gobi series and perhaps of Siwalik age.

Persia and Mesopotamia.—Boulder beds, gravels and shales, resembling deposits forming at the present time but which have undergone a slight disturbance, have been noted by Tipper, resting on all the older formations, in the Kirman province of eastern Persia.[46] It is, however, in southern Persia that we find a formation, the Bakhtiari series of Pilgrim, which in stratigraphical position

[41] Rec. 59, 118 (1926).
[42] G. E. Pilgrim, Rec. 40, 200 (1910).
[43] T. H. D. La Touche. Rec. 26 88 (1893).
[44] C. L. Greisbach, Rec. 20, 24 (1887).
[45] H. H. Hayden, Mem. 39, 30 (1911).
[46] Rec. 43, 67 (1921).

as well as in general character, is evidently the equivalent of some portion of the Siwalik sequence. The Kurd series of Mesopotamia is another equivalent.[47].

Chitral.—In the valley of Chitral river, there occurs continuously from near Galatak to Drosh a coarse, current-bedded grit or pebbly sandstone, with bands of conglomerate, exactly similar to members of the Upper Siwalik. It dips inwards towards the hills and is unconformably overlain by recent river deposits. Similar deposits are present at the junction of the Shishi and Chitral rivers, where they include also yellow and lavender clays. The same beds, largely removed by denudation, are also seen up the Chitral valley towards Chitral, sometimes as much as 500 feet above the present river bed.[48]

Waziristan.—In Southern Waziristan the Siwaliks are exposed around Jandola on the Takki Zam (Tank Zam) and in Northern Waziristan across the Tochi river some 18 or 18 miles east of Miram Shah.

In Southern Waziristan the beds dip westwards, in which direction they are mapped as faulted against the Eocene. The Kamlial stage as well as the underlying Murree is definitely absent, according to Coulson,[49] and no rocks resembling the Chinjis have been recognised. If lithological appearances can be trusted the beds range from the Dhok Pathan stage upwards, and would thus include the Middle Siwalik; the latter comprise sandstones with grits and conglomerates, and are faulted against Kirthar limestones south of Chagmalai Post. Upon these beds lies a succession consisting chiefly of conglomerates and soft sandstones, which Coulson suggests are Upper Siwalik. Stuart also believes all the younger Tertiaries of this area to belong to the Upper Siwalik and describes them as consisting almost entirely of coarse ferruginous conglomerates in which subordinate bands of red sandstone occur only very occasionally.[50]

In the Tochi valley the massive conglomerates and grits of the Upper Siwaliks are first seen two or three miles west of Tochi village, dipping gently eastwards under the Bannu plain. Westwards the dip steepens, in some places to verticality, and the rocks are seen to be underlain by older Siwaliks, and the latter by the Upper Nummulitic all of them with a persistent easterly and often nearly vertical dip. Several thousands of feet thick as the Upper Siwaliks must be, the thickness of the beds immediately below, whether Middle Siwaliks, Lower Siwaliks or both, is even greater and has been estimated to be about 10,000 feet. The conglomerates pass down gradually and conformably into finer sandy strata which at once become interbedded with beds of shale.[51] The older Siwaliks of this section consist entirely of such sandstones and shales, the for-

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[47] E. H. Pasoe, Mem. 48, 8 (1922).
[48] H. H. Hayden, Rec. 45, 280 (1915).
[49] Gen. Rep. Rec. 72, 72 (1937).
[50] Rec., 54, 92 (1922).
[51] F. H. Smith, Rec. 28, 107 (1895).

mer grey and the latter red in colour. Shales predominate in the upper portion of the older division but give place lower down to soft sandstones; at the base shale bands are wanting. No fossils have been recorded in any of the rocks. Although the general parallelism of the basal sandstone with the underlying white nodular limestone which here forms the uppermost member of the Eocene appears unquestionable, the upper surface of the limestone is not quite smooth and its irregularities are filled by the overlying sandstone, in the basal two feet of which, moreover, are many pebbles of the limestone.

Bannu and Kohat.—In Bannu and Kohat the Siwaliks are folded up with the Murree and Eocene beds between the Afridi hills and the Trans-Indus continuation of the Punjab Salt Range. The country is a succession of rugged sterile valleys interrupted by irregular hills of nummulitic limestone and salt. The Siwaliks thus cover a large proportion of what is known as the Trans-Indus Salt Region, a tract bounded eastwards by the Indus and westwards by the Kurram river which curves round to the southeast and east to cut across the equally curving folds of the Tertiaries before joining the Indus below Isa Khel. The higher zone of the Trans-Indus continuation of the Salt Range begins with a nearly N.-S. range of hills northeast of Kalabagh, including the peak of Dangot Sir and its cliffs overlooking the Indus, and another maximum point a dozen miles further north known as Bangali Sir, all made up of Siwalik sandstones and conglomerates. With a sharp bend to the west, assisted perhaps by a fault, these hills give place to the Lakhar Ghar, the crest of which extends W. S. W. to the mountain knot of Prangzai Sir. Thence it continues more or less westwards as the Chichali range which is pierced by the Chichali stream. Echelonned on the Chichali hills is the Shingarh range which curves southwards to the Kurram under the name of the Maidan range. Across the Kurram the line curves in a broad arc south-westwards as the Marwat hills and then north-westwards as the Bhattani range. The higher parts of all these ranges are built up of Siwalik strata, which also flank the Khasor, another range parallel to and southeast of the Marwat hills on the other side of the Paniala stream. In all the ranges which are more or less a Trans-Indus continuation of the Punjab Salt Range, it is very doubtful whether the Murree series is present at all.

In the Kohat Salt region, the Murrees, when present, pass up into the Siwaliks, the red colour of the former becoming rarer and limited to the clays and concretionary pseudo-conglomerates.[52] Higher up above the vague Murree-Siwalik boundary the clays assume a pink, drab or orange tint, while the sandstones, which are often of a glistening whitish-grey colour, become very soft and show strings of small pebbles; further up in the succession, the latter increase in size and quantity, the beds becoming thick, incoherent conglomerates or boulder beds.

[52]A. B. Wynne, Mem. 11, 165 (1875).

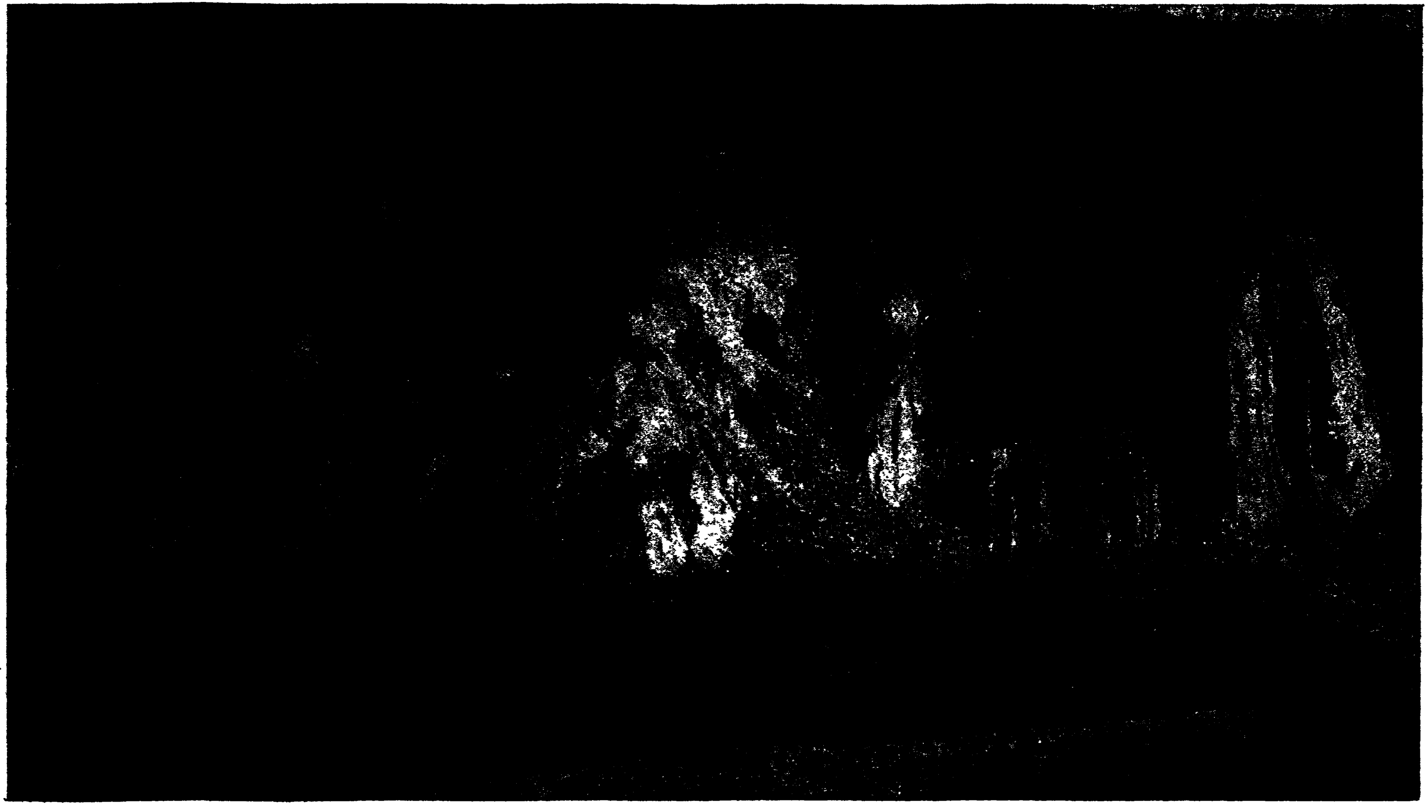
Estimates of the total thickness of the Siwaliks of this region vary. In the Trans-Indus Salt fields of central Kohat these beds range from 2,500 to 4,500 feet, but it is admitted that much of the series has been denuded away. In the near neighbourhood of Kalabagh a figure of not quite 10,000 feet is given by Wynne, but a little north-west the total can scarcely be less than 15,000 feet and may be as much as 17,000 feet; here again highest beds appear to lie concealed beneath alluvial deposits. In the Shekh Budin area sixty miles or so southwest of Kalabagh, the total thickness may be over 20,000 feet.

In the Kalabagh area the series has been divided into a "Lower" and " Upper " division, which it will be safer to speak of as older and younger groups, since the latter probably includes the Nagri stage of the Middle Siwalik; the boundary between the older and younger groups is described as indefinite.

The older group is described as consisting of grey and greenish sandstones, with bones teeth and fossil wood, and drab or reddish clays, reddish clays predominating below; in places the fragments of bone are said to be numerous and large. The lowest beds in the Kalabagh area, about 400 feet thick, are red clays and grey sandstones probably belonging to the Kamlial stage,[53] since they resemble closely beds in the same stratigraphical position and containing reptilian remains, in the Cis-Indus Salt Range.[54] Traced westwards and southwards they become reduced to a narrow band of red clay, which is only a few feet thick west of Isa Khel; similar red clays are often seen close to the base of the Tertiary sandstones in the Khasor range, where the Eocene is not represented. In places there is a basal conglomerate of Eocene limestone fragments. From Khushalgarh, further north on the Indus, the identification of *Dinotherium giganteum* ("D" *indicum* Falc.), *Sanitherium schlagintweiti* Meyer and *Listriodon pentapotamiae* Falc. indicates the presence of the Chinji stage.

The younger group is composed of soft, grey sandstones, and grey or orange-coloured clays, with conglomerates and occasional bones. The pebbles and boulders of the conglomerates are composed chiefly of crystalline rocks, igneous and schistose, believed to have been derived from the Himalaya and adjacent mountain systems to the north. The conglomerates are said to be most strongly developed in the near neighbourhood of the Indus and the Jhelum, and build the cliffs known as Kaffir Kot between the Kurram and Bahadur Khel; they appear to mark the passage of early progenitors of the two rivers. They waste into loose accumulations of smooth boulders which strew the ground over large areas in the Trans-Indus Salt Region. This younger group may include a more or less complete succession from the Nagri to the Boulder Conglomerate. The Nagri has ben recognised at Khushalgarh and has yielded *Conohyus indicus* (Lyd.) and *Amphieyon palaeindicus;* Lyd.; from a Dhok Pathan horizon at the same locality comes *Dorcatherium majus* Lyd. The

[53] Referred doubtfully by Wynne to the Murrees or the Nahans.
[54] A. B. Wynne, Mem. 17, 235, 243 (1880).



THRUST PLANE BETWEEN THE MURREES AND THE BOULDER CONGLOMERATE.

G. S. I., Calcutta.

Khushalgarh specimens also include *Sus hysudricus* Falc. & Cautl., perhaps from the Dhok Pathan horizon, and *Hemimeryx pusillus* Lyd., a species found in both the Chinji and Nagri.

In the Kalabagh area the basal red clays and grey sandstones are succeeded by 9,500 feet of brown clays and grey sandstones, and these in the Lun watercourse are seen to be overlain eastwards by the massive grey sandstones of the inaccessible Dangot cliffs, which form one of the gates of the Salt Range. The Dangot sandstone, 2,000 feet thick in one section, is mostly without clays, and has the peculiarity of weathering to show elongated cores of harder nature. It has been assigned to the Nagri, though bones are not numerous therein, and usually contains scattered pebbles or strings of pebbles, passing up by increase of pebbles into the conglomerates of Makhad, a town higher up on the other side of the Indus, of the Lakhar Ghar and of other places.

In the Marwat-Kundi range and Shekh Budin area of the Trans-Indus Salt Range, T. O. Morris has divided the severely folded and faulted Siwalik as follows:[55]

Malagan beds	2,200 feet seen,
Sheri Ghasha beds	2,500 feet seen,
Marwat beds	4,700-8,900 feet,
Kargocha beds	up to 10,000 feet.

In the middle of the Marwat beds Morris has traced what he describes as a typical glacial boulder bed for over 16 miles, with a maximum thickness of 70 feet. The Marwat beds, both above and below the boulder bed, have yielded *Elephas, Equus, Cervus, Giraffa, Bos, Hippopotamus*, gazelle, antelope, and other forms correlatable with the Villafranchian of Europe and the Kanam beds of East Africa. The Marwat beds, therefore, are partly or wholly equivalent to the Pinjor stage of the Siwalik sequence.[56]

The Siwalik series of the Potwar Plateau.—On the other side of the Indus, the Siwalik strata, together with more recent alluvial deposits not easily differentiated therefrom, occupy the greater part of the Potwar or Rawalpindi plateau, which stands about 1,000 feet higher than the adjoining alluvial plains, and is some 7,000 square miles in area. Between the raised edge or scarp of the Salt Range to the south and the Kala Chitta and Margala hills to the north, this tableland forms an unusually broad kind of *dun* similar in some of its characters to those referred to later as separating the foot-hills of the Himalaya from the higher portions of that chain. From the southern edge of the Muree belt, from which they are usually separated by a faulted contact, these Siwalik and younger deposits

[55] Q. J. G. S., Vol. 94, 387 (1938).

[56] That the Marwat beds are continuous laterally with the Cis-Indus Nagri stage, as suggested, is highly improbable.

stretch southwards to the Eocene (Kirthar) limestone which crests the Salt Range scarp. They do so, however, not without interruptions in the northern part of the tract by other faults which bring up one or two narrow bands of the Murrees and lowest Siwalik stages, and also by a few anticlinal inliers of the same beds. Southwards the folding becomes more open and the central portion of the tract is occupied by the broad shallow synclinorium of the Sohan river. In the southerly limb of this synclinorium, the N.N.W.'ly dip scarcely ever exceeds 10° and is frequently much less. The axis of this great depression lies parallel to and a little south of the Sohan river for nearly 90 miles. This elongated oval, asymmetric trough, 26 miles broad in its more central portion where its direction is approximately E.-W., swings up towards the northeast at its Jhelum end, narrowing steadily into a long curved neck until it is scarcely 5 miles across from crest to crest of its bordering anticlines.[57] Through Attock it can be traced across the Indus into the North-West Frontier Province, maintaining at the same time its genreal E.-W. direction unaffected by the acute northward bend of the Salt Range further south.[58]

In this basin has accumulated a vast pile of Miocene, Pliocene and Pleistocene fresh-water sediments. The various stages into which the Siwaliks are here divisible show a certain amount of overlapping, the Upper Siwalik and younger deposits especially having overlapped and obscured the structure towards the middle and southwestern parts of this geo-syncline. The topography of this tract is largely one of deep, ramifying, steep-sided ravines or *khadera* as they are called in vernacular, dissecting the country into a characteristic type of "Bad Lands". In the eastern part of the Potwar the Siwalik beds are disposed in broad parallel belts, functioning as denuded members of normal anticlines and synclines; here the lines of folding are described as showing great persistency, individual folds being traceable for 30 or 40 miles with but slight deviations of strike.

On the southeastern face of Mount Tilla in the eastern part of the Salt Range area, according to Wadia, the Siwaliks have been overthrust by Cambrian beds;[59] on the northwestern face, which is a dip-slope, a continuous, undisturbed sequence of Eocene, Murree and Siwalik is said to overlie the Cambrian with no angular discordance but with the intervention here and there of 6-8 feet of the Talchir Boulder Bed.

Subdivision.—One of the most accurate and detailed accounts of the Siwaliks of this region is from the pen of R. van Anderson[60] and this has been freely used in the following digest. The Siwalik series of the Potwar was originally divided into a Lower group

[57] D. N. Wadia, Mem. 51, 336 (1928).

[58] E. S. Pinfold, Rec. 49, 140 (1918).

[59] Gen. Rep. Rec. 65, 118 (1931).

[60] Bull. Geol. Soc. Amer., Vol. 38, 665 (1927).

of 10,000 feet and an Upper of 4,000 feet, but more detailed examination has resulted in a three-fold division as follows:[61]

Upper	Boulder Conglomerate stage.	?Cromerian (Lower Pleistocene).	Pleistocene.
	Pinjor stage.	Villafranchian.	
	Tatrot stage.	Astian.	Pliocene.
Middle	Dhok Pathan stage.	Pontian.	
	Nagri stage.	Sarmatian.	Middle to Upper Miocene.
Lower	Chinji stage.	Tortonian.	
	Kamlial stage.	Helvetian.	

Continuity of deposition.—A large proportion of the Siwalik sequence is composed of alternating bands of sandstone and of argillaceous material, usually varying from 70 to 120 feet thick; a very frequent thickness is about 100 feet, but some of the bands are occasionally much thicker, and these figures (Wynne) are but a rough average. There are small local unconformities, and thinning out and overlap are frequent, but these irregularities are no more than are to be expected in a sub-aerial series. There has been no widespread break in deposition and, in spite of considerable lateral variation in individual beds, the above general sequence is remarkably constant. Each stage, corresponding to a slight change in the conditions of deposition, grades in most places conformably into the next across a transition zone which may be 200 and sometimes as much as 500 feet thick. In the Salt Range area a larger break than usual has been inferred by some to exist between the Middle and Upper Siwalik, but this, if it be of any appreciable size, can only be of local significance, for nothing is more certain than that, in some part or other of the riverine belt between the sub-Himalayan hills and the Arabian Sea, there has been deposition since the beginning of the Miocene epoch. Local interruptions, as a result of the steepening of the gradient or lateral shifting of the flood plains, may have taken place here and there, but these must be represented by deposition in other parts of the belt. Part of the Siwalik sequence lies beneath the overthrust older rocks of the Himalaya, but portions so concealed are most likely to belong to the oldest stages and, in any case, it is improbable that any stage or any appreciable fraction thereof is everywhere unrepresented in exposed portions elsewhere. In any cross-section of the Siwalik belt, even local interruptions are unlikely to have been of the length of a stage or of any substantial part thereof. The Siwalik river continued to flow throughout the Siwalik period and it is inconceivable that it should have ceased depositing simultaneously throughout its entire course for even a short period. Pseudo-conglomerates, the nature and probable origin of which are discussed below, are very seldom found in the Upper Siwaliks. On the other hand, they are a universal characteristic of the Lower Siwalik from Sind through the Bugti Hills and the Potwar Plateau to the Kangra and Simla areas, and occur in thick masses

[61] G. E. Pilgrim, Proc. 12th Ind. Sci. Congr. p. 202 (1925).

in the Middle Siwaliks of the Potwar. If they coincide with countless small unconformities as Pilgrim has suggested, it follows that the period of sedimentation of the Lower and Middle Siwaliks must have been considerably longer than the thickness of the beds would lead one to infer. In fact, the 6,000—6,500 feet of Lower Siwaliks and the 8,300 feet of Middle Siwaliks may have severally taken much longer to accumulate than the Upper Siwaliks which in their fullest development in the Siwalik Hills (10,000 feet), are thicker than either of the earlier divisions.

Pseudo-conglomerates.—The term "pseudo-conglomerate" was originally applied to a rock having the appearance of a conglomerate but whose pebbles, of calcareous character, were believed to be of concretionary origin. It has since been used for beds made up principally of pebbles of clay and, although there is in many cases no reason to doubt the truly clastic or conglomeratic nature of these beds, there has been some excuse for the somewhat indiscriminate use of the term pseudo-conglomerate for them, since, not only is it sometimes difficult to distinguish a clastic from a concretionary structure in such beds, but in several instances there is reason to conclude that both are present in the same rock. In other words, some of the types recorded as "pseudo-conglomerates", are both conglomeratic and pseudo-conglomeratic. One of the latest and ablest descriptions of these peculiar rocks is again from the pen of Anderson. The deposit, occurring in beds or irregular cross-bedded lenses, consists most commonly of a calcareous sandy matrix containing lenses of siltstones, and full of hard pellets, 2-5 mm. across, of grey yellowish or reddish brown limestone or calcareous siltstone and ochreous material; less often the pellets or pebbles are of a calcareous sandstone. The proportion of pebbles to matrix varies enormously—according to Krynine, from 2 to 95 per cent.[62] While some of the pellets and nodules appear to be of a concretionary character, others, varying from a minority of rounded or sub-angular pebbles to a majority of angular rock fragments, usually of a flattish shape, show evidence of consolidation prior to their deposition; these clastic fragments can be matched among the adjoining siltstones and sandstones from which they were evidently derived, and differ only in being somewhat more calcareous. The inclusions, which are often ferruginous as well as calcareous, tend to be more highly coloured than the matrix, and more indurated than the average sediment of the formation. According to Krynine, types including both hard pebbles of quartzite, limestone, chert, re-worked hematitic concretionary material, derived presumably from an old soil deposit as well as soft pebbles of siltstone or sandstone, are sometimes seen, especially in the Tatrot stage of the Siwalik. The beds and lenses of pseudo-conglomerate range up to many feet in thickness and hundreds of feet in length. As Anderson notes, this type of deposit is probably a result of sub-aerial exposure, surface concentration of cementing agencies, and drying and cracking of the silts exposed; the latter processes would lead to re-working

[62] Amer. Journ. Sci., Ser. 5, Vol. 43, 434 (1937).

and re-deposition elsewhere through the agency of wind and running water. In discussing the origin of these beds, Pilgrim has suggested that the concretionary structure was produced in each particular band before the deposition of the next layer of sediment. This is presumed to have taken place during periods—perhaps long periods —of entire or almost entire cessation of flood alternating with periods during which floods were of constant, probably annual, occurrence over the vast flood plains on which, there is every reason to believe, the Siwalik sediments accumulated.[63] During the periods of rest, large tracts must have remained almost dry and subject to atmospheric influences, capillarity and evaporation; in fact they were exposed to conditions such as determine the formation of *Kankar* in the plains of Bengal and elsewhere in India and Burma today. The concretionary band would thus represent a *quasi*-lateritic soil layer of greater or lesser thickness according to whether it had remained subject to atmospheric influences for a longer or shorter time. Naturally the layers of sediment exposed during the periods of desiccation would vary somewhat in lithological character and would give rise to different varieties of concretionary bands, although the nature of the concretionary action seems to have been in general the same. The small ferruginous pellets in some of the bands give them a close resemblance to the pisolitic varieties of laterite. There is little doubt in the writer's mind that a large proportion of the deposits recorded as "pseudo-conglomerates" in the Murrees and Siwaliks, are of clastic origin and, in that respect, true conglomerates in which the pebbles are of soft clay or siltstone instead of harder endurable material. The pebbles of such beds, in fact, differ from those of typical conglomerates in having suffered no appreciable transportation and in being incapable of surviving the disintegration of their matrix.

Petrography of some of the Siwalik sediments and deductions therefrom.—In an interesting paper on the petrography and genesis of the Siwalik series,[64] P. D. Krynine notes that the composition of the Siwalik sandstones is usually constant and throughout the whole thickness of over 20,000 feet closely approaches an average content of 40 per cent. quartz, 15 per cent. felspar, 6 per cent. mica (mostly biotite) and from 35 to 40 per cent. of metamorphic rock fragments in the form chiefly of schist and phyllite; the metamorphic rock fragments are finely comminuted and hence usually visible only with the aid of a microscope. This composition is described as very constant in spite of the variation in appearance of the rocks. The quartz grains of these rocks are rarely rounded and generally angular, even sub-angular forms being infrequent; this is proof of very rapid erosion and deposition. About half these grains show strong strain shadows. The grains of felspar are made up of both potassium felspar (mostly microcline) and plagioclase (mostly oligoclase) in more or less equal proportions. These are also angular to subangular.

[63] Rec. 43, 271 (1913).

[64] Amer. Journ. Sci. Ser. 5, Vol. 34, 422 (1937).

though somewhat more rounded than the quartz grains, and show in the same specimen all degrees of alteration from perfectly fresh transparent grains to almost opaque fragments. The micas also show all stages of alteration in the same slide. Krynine describes the heavy mineral suite as rather poor and monotonous. Among the minute rock fragments which, as has already been said, are almost exclusively of metamorphic rocks, the following have been recognised: biotite-quartz schist (the most abundant type), muscovite-quartz schist, ordinary quartz-schist, two-mica schist, chlorite-schist, epidotised quartz-schist, sericitised schist, various phyllites, graphitic schists. high-rank slates and varieties of quartzite. Minute pieces of red sandstone and chert are also present. Limestone and chert fragments are especially abundant in the Murrees and the Upper Siwaliks. Some of the Nagri sandstones, as well as some of the red sandstones and mudstones from the Chi[illegible]ere found by Krynine to show evidence of post-depositional sub-aerial weathering, causing the formation of already mentioned small red authigenic hematite concretions surrounded by hematitic haloes.

In the still more minute grains of the mudstones and shales Krynine found 80 to 100 per cent. to consist of quartz, 3-5 per cent. of felspar, and nearly all the rest, sometimes as much as 20 per cent., of metamorphic rock fragments.

At the top of the Dhok Pathan, at Andar Kas, are a few feet of a very fine-grained. soft, loess-like, yellow silt which, from the heterogeneous helter-skelter disposition of its mica flakes and quartz grains, is believed by Krynine to have been wind-borne, and to indicate a drier climate.

As the Himalaya continued to rise, precipitation not only would have increased but seasonal changes would have become more sharply contrasted. This increased rainfall and development of seasons have left their mark in the impurity of the Murree and earlier Siwalik sediments resulting from the lack of any notable sorting action, in comparison with the greater purity. the greater general coarseness and evidence of sorting action, seen in the later Siwalik stages. The finer sediments in the Upper Siwalik may well have come from the Indian peninsula to the south.

An interesting attempt by Lewis to reconstruct the conditions which prevailed generally during the Siwalik period in the riverine tract along the foot of the growing Himalayan range may be summarised as follows. In the first place Lewis divides the Siwalik fauna as a whole into three types:[65]

(i) River-bank and aquatic fauna,

(ii) Forest fauna,

(iii) Savannah, steppe or veldt fauna.

Among the Proboscidea are the dinotheres and primitive trilophodonts, which have teeth adapted to eat only succulent herbage

[65] Paul D. Krynine, Amer. Journ. Sci., Ser. 5, Vol. 34, 441 (1937).

and are water-loving types characteristic of a warm humid lowland; the higher elephants were fitted for a more rugged country and harsher vegetation. Of the Equidae, the Indian species of *Hipparion* have broader hooves than any others, the lateral digits being exceptionally well developed. For these reasons they are thought to represent a savannah or swamp type of the genus; *Equus* was better adapted to harder ground and harsher herbage. Among the Bovidae, the presence of antelopes suggests prairies, steppes or desert, while that of goats and oxen points to a less arid environment. The aardvark or *Orycteropus* on the other hand indicates that at one part of the period rainfall was scanty and conditions arid or even desert. The water-deer or tragulids were river-bank denizens, and the hippopotamus suggests river bottoms. The majority of the pigs and Canidae were forest dwellers, though a few of the former from the Chinji to the Dhok Pathan show marked adaptation for increasingly arid conditions. *Giraffokeryx* seems to have been a forest form, but the giraffes prefer open grass lands with scattered trees. In general, therefore, we may visualise during most of the period belts of luxuriant forest and open grass plains, with a great river winding through one or the other.

THE LOWER SIWALIK.

Kamlial stage.—The lowest or Kamlial stage belongs lithologically as much to the Murree series as to the Siwalik and was originally mapped with the Murrees by Wynne. The boundary between the two is vague and not easy to recognise. The passage from Upper-Murrees to Kamlials is described by Cotter as one from softer sandstones and brighter and redder clays to harder sandstones and darker coloured clays; the succession becomes more arenaceous and pseudo-conglomerates increase in frequency. In Khaur and some other localities the Kamlials are distinguished from the Murrees by abundant vertebrate remains, but this distinction has been found by Lahiri to be less pronounced in west Attock where the Kamlials are less fossiliferous and the Upper Murrees have yielded several fossil horizons.

The type area of the Kamlial stage [66] is the Khaur dome, east of Pindigheb, where the ridges of Kamlial sandstone form oval rings round the central small elliptical outcrop of Murree beds; the thickness here is about 1,000 feet. The Kamlial rocks appear in a zone of outcrops to the north of Khaur and Pindigheb, stretching from the Indus west of Jand, with echelonned interruptions to the country south of Rawalpindi and thence across the re-entrant of the Jhelum into Jammu,[67] their thickness here ranging from 1,000 to

[66] The name is a little unfortunate since the village of Kamlial itself stands on the next higher stage, the Chinji. The Kamlials appear at times to have been misidentified as Fatehjang beds.

[67] E. S. Pinfold, Rec. 49, 154 (1918).

2,000 feet and increasing from west to east;[68] this zone includes the Chirpar hills which are made up of Kamlial and Murree rocks and in which the ridge-forming propensities of the former are well displayed in steep ramparts of rock 80 or 100 feet high. Southwards from Khaur there appears to be no appreciable diminution in thickness, for, along the northern fringe of the gently north dipping nummulitic limestone capping the Salt Range, 34 miles away, the Kamlials are still estimated to be 900 feet thick and upwards, and extend for over 120 miles along the range. In this belt the more typical Kamlial rocks are separated from the Eocene beneath by some red beds which may perhaps represent the topmost layers of the Murree series. Anderson gives the combined thickness of the Kamlials and these doubtful red beds as 1,400 feet near the Indus, 1,000 feet at the sharp Sakesar bend and highest point of the Salt Range, increasing eastwards to 1,300 feet in the central portion of the range, to 1,550 feet near Kalar Kahar (excluding 500 feet of prominent transition beds at the top), and to 2,070 feet in the Diljaba ridge; on Mount Tilla, some 12 miles south of Diljaba this combined thickness is 1,800 feet, but on the Chambal ridge a little further south it is only 900-1,000 feet.[69] In the Bakrala anticlinal ridge, a northeasterly continuation of Diljaba, a total of 2,000 feet has been estimated, of which 1,100 feet are doubtfully assigned to the Murrees on the grounds of their purplish colour and the predominance of siltstone, but which nevertheless contain abundant vertebrate bones.[70] A similar thickness of 2,011 feet has been measured in a boring for oil at Jhatla, some ten miles north of the central part of the Salt Range.

According to Pilgrim, the Kamlial, like the Chinji is characterised by the prevalence of pseudo-conglomerate which is of two types, (i) a more or less hard, compact and very calcareous type similar to that found in the Nahans of the sub-Himalaya and, (ii) a much softer and less calcareous kind, more like types found in Sind and the Bugti hills.[71] Anderson describes the Kamlial stage as consisting in the main of resistant, ridge-forming sandstone, composing on the average about four-fifths of the formation, in individual beds which range in thickness up to 100 feet and more; the remaining fifth is made up of less prominent siltstones of more or less argillaceous character, ranging from a few inches up to 30 feet and occasionally over; towards the eastern end of the Salt Range the proportion of argillaceous silt increases greatly. The beds, whether of sandstone or shale but especially of the former, may be regarded as lenses varying from a few feet up to a few miles in lateral extent. The sandstones are mainly grey or greenish grey but sometimes, and especially in the lower horizons of the stage, reddish or purplish in colour;

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[68] It is possible that the thickness here given may include Upper Murree beds: whether this is so or not, the Kamlials are believed to thicken northwards from Khaur.

[69] Pilgrim gives a thickness of 1,700 feet, presumably in the longitude of Chinji (Rec. 43, 267 (1913).

[70] R. V. V. Anderson, Bull. Geol. Soc. Amer., Vol. 38, 685 (1927).

[71] Rec. 43, 267 (1913).

they weather to a darker tint than do the Murree sandstones. Long jagged ridges of tough sandstone, extending for miles across the country, form a marked feature of Kamlial topography, the beds below and above being more argillaceous and softer in character. In places the sandstone is quarried for building purposes (Wadia). Many of the sandstones are pseudo-conglomeratic. The siltstones or shales show the same colours as the sandstones, but reddish and purple tints predominate over the green; they are not as a rule nodular.

From the Kamlials of the Potwar area has been collected a fauna which, on the evidence of *Hyaenaelurus*, of a large species of *Anthracotherium*, and of a bunodont species of *Listridon* (*L.* cf. *guptai*), has been referred to the Helvetian;[72] it is the same as that found at the base of the fresh-water Manchhars of Sind:

Gastropod opercula.[73]

REPTILIA.[73]

Crocodile teeth.

CHELONIA.[73]

Trionyx sp.,
Emys sp.

CARNIVORA.

Amphicyon cf. *shahbazi* Pilg.,
Hyaenaelurus lahirii Pilg.

PROBOSCIDEA.

Dinotherium giganteum Falc. & Cautl. (Genus found in the Lower Miocene of Europe),[74]
Trilochodon cf. *angustidens* (species found in the Lower Miocene of Europe and North Africa).

PERISSODACTYLA.

Chalicotherium sp. (not the Chinji species).

ARTIODACTYLA.

Anthracotherium sp. (a large species),
Hyoboops palaeindicus Lyd.,
Hemimeryx cf. *pusillus* Lyd.,
Hemimeryx (?) *blanfordi* Lyd.,
Hyotherium sindiense Lyd.,
Listriodon pentapotamiae Falc.,
Listriodon cf. *guptai* Pilg.,
Conohyus cf. *sindiensis* (Lyd.),[75]
Small antelopes,[76]
Anthropoid ape—molar.[77]

[72] Pilgrim, Private Communication; Also Pal. Ind. New Ser., Vol. 8, No. 4, 36 (1926); Rec. 61, 197 (1928); Mem. 55, 109 (1932).
[73] Rec. 58, 61 (1925).
[74] Rec. 61, 197 (1928).
[75] Rec. 61, 198 (1928).
[76] Rec. 58, 61 (1926).
[77] Rec. 58, 61 (1926).

The Chalicotheres were aberrant perissodactyls of rhinoceros-like proportions, but with the slender neck, small head and inoffensive character of the horse, with the muzzle and front teeth of a ruminant but with molars which combine the characters of a browsing animal like the rhinoceros or giraffe with those of an omnivorous animal like the pig, bear or ape. They are inferred to have had habits analogous to those of the rhinoceros, lacking the defensive armour and offensive weapons of that group but having the ability to dig for roots and tubers as well as for water, and thus to supplement their food of leaves, twigs and coarse grass.[78]

Chinji stage.—Towards the top of the Kamlial the proportion of argillaceous matter increases and the Chinji stage which follows and which is named after a village seventeen miles south of Talagang, is predominantly an argillaceous one. Along the northern flank of the Salt Range a belt of those beds, over 100 miles long, follows the Kamlials, having like them a gentle general dip northwards beneath the next or Nagri stage. A Y-shaped outcrop includes the Khaur and Dhulian domes, forking round Pinidigheb, and arm of the Y being prolonged to the Indus and beyond, widening greatly in the neighbourhood of the river. North of the Y are three or four strip-like outcrops of Chinjis, one of them, south of Mianwala, having a maximum breadth of 4½ miles. One of them stretches eastwards to the south of Rawalpindi; other exposures are seen in the east Potwar and occupy considerable areas in the Jhelum re-entrant. From 1,400 feet in the Salt Range area it expands to three times that thickness and more in the northern part of the region under consideration. Around Khaur it is estimated to be about 4,000 feet,[79] but to the west it thins out. In the belt south of Mianwala, a few miles farther northwest, it may be as much as 4,500 feet but this outcrop is in highly folded country and there may be some reduplication. At the type area it is 2,100 feet, while in the Jhatla boring, nine miles farther north, it measured 2,807 feet. Pilgrim gives the total thickness, presumably at the type area, as 2,300 feet, assigning 1,500 feet to the lower and 800 feet to the upper Chinji. West of Kalar Kahar, the stage is about 2,600 feet, though suffering attenuation at Kalar Kahar itself.[80]

The Chinji is one of the most easily recognisable stages of the Siwalik series owing to its prevailing brick-red or brown orange colour and to the sunken relief and labyrinthene dissection of its topography. The latter feature is due to the predominance of argillaceous material. In the southern belt the percentage of warm, brick-red siltstone or sandy clay in the formation averages about 70 and, though less than this in the north, is still above 50. These beds are regularly and picturesquely banded with lesser beds of ash-grey sandstone. The colour of the siltstone varies in depth of shade from yellowish to purplish hues, while the sandstone often assumes an

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[78] W. D Matthew, Bull. Amer. Mus. Nat. Hist., Vol. 56, 524 (1929).
[79] Gen. Rep. Rec. 65, 120 (1931).
[80] G. de P. Cotter, Mem. 55, 110 (1933).

olive but only occasionally a purplish colour. While the sandstone bands rarely attain a fifty-foot thickness, the silt bands may be as much as 200 feet across; the average thickness of the bands of both forms of rock, however, is respectively less than these maxima. Occasionally dark layers of magnetic sand are seen in the sandstones, but this is a feature more characteristic of the following stage. Scattered pebbles, usually of quartzite, are not infrequent in the sandstone. Lenses of pseudo-conglomerate are scattered through the Chinji beds and occur particularly in their basal portion; they are, however, thinner and less abundant than they are in the more dominantly sandy stages of the Lower and Middle divisions. From the Chinjis of this area come:

LAMELLIBRANCHIATA.

Lamellidens sp. nov.,
Indonaia sp. nov.,
Parreysia sp. (Prashad).

PRIMATES.[81]

Bramapithecus thorpei Lewis.,
Bramapithecus punjabicus (Pilg.),
Sivapithecus sivalensis (Lyd.),
Sivapithecus indicus Pilg. (only in the Upper Chinji, placed by Pilgrim in the Hominidæ).[82]

RODENTIA.

Kanisamys indicus A. E. Wood,[83]
Rhizomys lydekkeri Hint.[84] (locality and stage unknown, but said to come from the "Lower Siwalik").
[84] *Paraulacodus indicus* Hint. (Upper Chinji, Salt Range),
Pectinator sivalensis Hint..
Theridomys sp. (fragmentary jaw; an European Tertiary genus),
Sivacanthion complicatus Colb.

PROBOSCIDEA.

Dinotherium giganteum Falc. & Cautl. (including "*D. pentapotamiae*" and "*D. indicum*"),[85]
Dinotherium sindiense Lyd.,
Trilophodon chinjiensis Osb.,
Trilophodo macrognathus (Pilg.),
Trilophodon ptychodus (Osb.),
Tetralophodon falconeri (Lyd.),
Tetralophodon properimensis (Osb.),
Serridentinus hasnotensis Osb.,
Serridentinus metachinjiensis Osb.,
Serridentinus browni Osb.,
Serridentinus chinjiensis Osb.,
Serridentinus prochinjiensis Osb..
Choerolophodon corrugatus (Pilg.),
Synconolophus dhokpathanensis Osb.,

[81] Amer. Journ. Sci. Ser. 5, Vol. 34, 141-144 (1937).
[82] Rec. 45, 34 (1915).
[83] Amer. Journ. Sci. Ser. 5, Vol. 34, 68 (1937).
[84] Ann. Mag. Nat. Hist. Ser. 10, Vol. 12, 621 (1933).
[85] R. W. Palmer, Pal. Ind., New Ser., Vol. 7, Mem. 4 (1927).

PROBOSCIDEA—*contd.*

Stegolophodon cautleyi, var. *progressus* Osb.,
Stegolophodon nathotensis Osb.

CARNIVORA.[86]

Martes ("*Mustela*") *lydekkeri* (Colb.),
Dissopsalis carnifex Pilg., (genus typically Eocene; a peculiarly primitive Creodont survival),
Dissopsalis ruber Pilg., (Matthew considers this synonymous with the preceding),
Amphicyon palaeindicus Lyd.,
Amphicyon pithecophilus Pilg.,
Vishnucyon chinjiensis Pilg.,
Sivanasus palaeindica Pilg.,
Eomellivora (?) *necrophila* Pilg.,
Vishnounyx chinjiensis Pilg.,
Sivalictis natans Pilg.,
Viverra (?) *chinjiensis* Pilg.,
Lycyaena (?) *proava* Pilg.,
Crocuta carnifex (Pilg.) (more primitive than *C. eximia* and *C. variabilis*),
Vinayakia sarvophaga Pilg.,
Sansanosmilus (?) *serratus* Pilg.,
Sansanosmilus (?) *rhomboidalis* Pilg.,
Sivasmilus copei Kretz.,
Sivaelurus chinjiensis Pilg.,
Vishnufelis laticeps Pilg.

PERISSODACTYLA.

Hipparion theobaldi (Lyd.) (in lower as well as upper Chinji; first appearance of the genus),
Gaindatherium browni Colb., (probably an ancestor of the *Rhinoceros*, retaining primitive characters which cause it to resemble in some respects *Dicerorhinus sumatrensis* Colbert,
Aceratherium perimense (Falc. & Cautl),[87]
Chilotherium blanfordi (Lyd.), ("*Teleoceras blanfordi*"),
Chilotherium intermedium (Lyd.).

ANCYLOPODA.

Macrotherium salinum F. Cooper,
Chalicotherium or *Macrotherium*.[88]

ARTIODACTYLA.

Microbunodon silistrense (Pentl.) (=*Anthracotherium* (*Microselenodon*) *silistrense* or *Anthracotherium punjabiense* Lyd.),
Hemimeryx pusillus Lyd.,
Pecarichœrus orientalis Colb. (The peccaries and pigs probably had a common ancestor in Eurasia),[89]
Palaeochœrus perimensis (Lyd.),
Listriodon pentapotamiœ Falc. (Genus abundant and characteristic),
Listriodon theobaldi Lyd.,[90]
Palaeryx sp. (a large antelope),[91]
Conohyus chinjiensis Plig.,

[86] Pal. Ind., New Ser., Vol. 18, 11 (1932).
[87] Generic determination questioned by W. D. Mathew who prefers to regard the specimen as belonging to a form related to *Chilotherium*.
[88] W. D. Matthew, Bull. Amer. Mus. Nat. Hist. 56, 453 (1929).
[89] E. H. Colbert, Amer. Mus. Novit, 635 (1933).
[90] G. E. Pilgrim, Pal. Ind., New Ser. 8, No. 4 29 (1926).
[91] G. E. Pilgrim, Rec. 43, 287 (1913).

ARTIODACTYLA—*contd.*

Conohyus indicus (Lyd.),
Conohyus sindiensis (Lyd.),
Propotamochœrus salinus Pilg.,
Propotamochœrus ulignosus Pilg.,
Lophochoerus exiguus Pilg.,
Dicoryphochœrus chisholmi Pilg.,
Dicoryphochœus haydeni Pilg.,
Dicoryphochœrus instabilis Pilg.,
Dorcabune anthracotheroides Pilg.,
Dorcabune hyaemoschoides Pilg.,
Dorcatherium minus Lyd. (determination of this and the following species somewhat doubtful),
Dorcatherium majus Lyd.,
Progiraff sivalensis (Lyd.),
Giraffokeryx punjabiensis Pilg.,
Giraffa (?) *priscilla* Matth.,[12]
Sanitherium cingulatum Pilg. (restricted to the basal Chinji; Matthew equates it with *S. schlagintweiti* Meyer,[13]
Gazella cf. *superba* Pilg.,[14]
Sivoreas eremita Pilg.,
Sivaceros gradiens Pilg.,
Strepsiportax gluten Pilg.,
Strepsiportax chinjiensis Pilg.,
Helicoportax praecox Pilg.,
Helicoportax tragelaphoides Pilg.

Fossils have been obtained from many horizons throughout the Chinji stage. The predominant groups in the Chinji fauna are dinotheres, primitive trilophodonts, forest-dwelling suidae, the Okapi-like *Giraffokeryx* water deer, innumerable crocodiles, a plethora of pythons, some of gigantic dimensions, turtles, monitor lizards and aquatic birds—an asseblage indicating a tropical humid climate with a heavy rainfall.

A few land shells are represented, mostly by the opercula of empullarid gastropods. The Chinjis, especially those of the eastern Potwar, are characterised by prolific chelonian remains, the most frequent being limb bones, vertebrae, skull bones and costal plates of *Trionyx*, *Emys* and other fresh-water turtles. The genus *Dinotherium,* found in this stage, is not apparently limited to the lower Siwaliks but, according to Pilgrim, undoubtedly survives into the Middle Siwalik (Dhok Pathan). The Rodent genera *Paraulacodus* and *Pectinator* are interesting as representing genera now confined to Africa. *Chilotherium* was a hornless, grazing rhinoceros, with a short, massive body raised but little above the ground, and having strong resemblances to a pig; it has a three-toed foot, a comparatively large head and two strong tusk-like incisors in the lower jaw, and seems to have been adapted for a steppe country with occasional swamps. So far as known, the genus, *Giraffokeryx*, is confined to India. It shows affinity to the Chinese Pontian species *Palaeotragus quadricornis* Bohlin. Pilgrim, while admitting this,

[12] Bull. Amer. Mus. Nat. Hist., Vol. 56, 537 (1929).

[13] *S. Sehlagintweiti* H. Von Meyer has been found in beds of a similar level on the West bank of the Indus, at Khushalgarh.

[14] Pal. Ind., New Ser., 26, Mem. I, 36 (1939).

suggests that *Giraffokeryx* may have given rise to the sivatherines of the Pontian and Dhok Pathan.[95]

The European correlation of the Chinji and other Siwalik stages is a question upon which opinion is divided, the tendency of American observers being to raise these stages to younger levels than those allotted to them by Pilgrim. Although the precise correlation of vertebrate faunas, bearing as it does on questions of migration, land connections and climate, is perhaps more important than that of marine faunas, space forbids more than a brief summary of the argument.[96]

The American argument is based mainly on the presence of the three-toed horse, *Hipparion,* specimens of which, though rare, occur in the Upper Chinji ; it is claimed that the genus has also been found in the Lower Chinji. *Hipparion* is regarded unanimously as having evolved from *Merychippus* in North America and in that country makes its first appearance as such in beds which American authorities have correlated with the Sarmatian of Europe. If, therefore, we accept this inter-correlation and assume at the same time that *Hipparion,* by way of Europe, reached India as a migrant from North America, it could not have arrived there before the Sarmatian epoch, and the Chinji could not be older than Sarmatian. While Lewis places it in the Sarmatian, Colbert makes it still younger and assigns it to the Pontian.

If, with the same assumption, an earlier age for this stage be accepted, it is necessary to conclude with Pilgrim that *Hipparion* had a dual origin and evolved in two separate centres from two different species of *Merychippus,* a supposition which, in the opinion of Colbert, "calls for too great a degree of parallel evolution to be compatible with our wonderfully complete knowledge of the actual material demonstrating the evolution of the horse".[97] There is some cogency in the American argument, but the alternative to Pilgrim's views presupposes that the great bulk of the Chinji fauna is a relict fauna, and the wholesale survival on such a scale is found by some difficult to accept. It seems inexplicable that *Hipparion* should have been the only member of the rich Pontian fauna of Europe, Persia and central Asia—the equivalent of the Chinji according to Matthew and Colbert—which succeeded in reaching India contemporaneously.

Pilgrim, Colbert and others have shown that many of the Chinji species are very closely allied to Tortonian forms ; this is well seen in the case of the general *Macrotherium, Amphicyon* and some of the Primates, as well as among the Chinji Suidae which, as Pilgrim remarks, include species of *Listriodon, Conohyus* and *Palaeochœrus* almost too close to Vindobonian (Tortonian) species of Europe to be called relics instead of migrants. Pilgrim's argument is supported by

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[95] Pal. Ind., New Ser., 18, 8 (1932).

[96] G. E. Lewis, Amer. Journ. Sci. Ser. 5, Vol. 33, 191 (1937) and especially E. H. Colbert, Trans. Amer. Phil. Soc., New Ser. 26, 21-27 (1935).

[97] Trans. Amer. Phil. Soc. New Ser., 26, 23 (1935).

the undoubted resemblance between the Dhok Pathan fauna and the European Pontian, and by the intermediate position which the Nagri fauna occupies between the faunas of the Chinji and Dhok Pathan. Not only does this correlation make the Chinji fit more easily into a Tortonian level, but it makes it difficult to understand how a Pontian fauna could be represented in two Indian stages, either contiguous (according to Lewis) or separated from each other by another stage over 5,000 feet in maximum thickness (the Nagri—according to Colbert). Pilgrim's view is that India either formed part of, or was very close to, an adaptive centre which gave origin to one branch of *Hipparion,* just as it seems to have done to the elephantoid branch of the Proboscidea and to the oxen and buffaloes. In this way the Indian *Hipparion,* and possibly also the European, may have originated from some region in central Asia not yet known. Both Pilgrim and Matthew consider that the nearest European equivalent to the Chinji fauna is that of La Grive St. Alban. The former at the same time admits the possibility that the Chinji bridges the abrupt gap between the La Grive St. Alban fauna and the Sarmatian, though this would scarcely account for the pre-Sarmatian migration of *Hipparion* from N. America into Asia. Space forbids a prolonged consideration of this interesting but controversial question but it seems at least permissible to put the following points. There is closer resemblance between the Indian Chinji and the European Tortonian than there is between the European Tortonian and its supposed American equivalent. There is also a closer resemblance between the Indian Dhok Pathan and the European Pontian than there is between the European Pontian and the supposed American equivalent. This being so, is there not more incentive to shift the American stages rather than the Indian in order to reconcile the facts?

On the east side of the Chambal ridge at the extreme eastern end of the Salt Range, there occurs, between the Chinji and Middle Siwalik and associated with a nodular clay, a pisolitic ferruginous band which has yielded only *Hipparion* remains. These beds are included with the Upper Chinji but appear to form passage beds between this formation and the Nagri stage of the Middle Siwalik. In other parts of the Potwar they are apparently represented by a break between the Chinji and Nagri beds. They probably correspond to the Nurpur zone of the Siwalik hills and the Kangra and Simla Hill States (p. 1793).

MIDDLE SIWALIK.

The Middle Siwaliks reach a maximum thickness of 6.000 feet north of Khaur but are subject to great lateral variation in thickness as well as in lithology; in the eastern Potwar they are said not to exceed 4.000 feet. Forty miles west of Khaur, on the north flank of a faulted anticline near the Indus, these beds are reduced to about 3,500 feet, while at a similar distance east of Khaur they are not much over 2.000 feet. According to Anderson, this thinning of the Middle is accompanied by a thickening of the

Upper Siwaliks. The lower limit of the Middle Siwalik is comparatively well defined; its separation from the Upper Siwalik seems to have given difficulty in some places, but in others the line of division is sharp both lithologically and faunistically. In the western Potwar the Middle Siwalik is essentially a sandstone formation with masses of pseudo-conglomerate, but towards Rawalpindi argillaceous material increases until it forms about half the total volume. Southwards also the division becomes less sandy and thins out to 4,560 feet in the country east of Kalar Kahar.[98] Several belts of the Middle Siwaliks have been mapped by Wadia in the eastern part of the Potwar and the syntaxial area, either rising synclinally on the Lower or pitching anticlinally beneath the Upper divisions. A noteworthy feature of the Middle Siwalik sandstones in this and other area is the large proportion of grains of magnetite and other heavy minerals; coarse grains and even stringers and thin laminae of magnetite, accompanied by ilmenite, epidote, garnet and others, are said by Wadia to be commoner in these sandstones than they are not only in the Murrees, Kamlials and Chinjis, but also in the Upper Siwaliks.

Nagri stage.—Of the two stages—Nagri and Dhok Pathan—into which the Middle Siwalik has been divided, a good description is given by Cotter.[99] The former, a predominantly arenaceous group with something like 80 or 85 per cent. of sandstone, is exposed along the northern flank of the Salt Range, its outcrop following in regular sequence that of the Chinji and widening greatly eastwards. North of the Sohan synclinorium outcrops of the Nagri beds enwrap those of the Chinji around the Khaur, Dhulian and other domes. On the southern flank of the Dhulian dome and to the west of Pindigheb, the maximum thickness of the Nagri stage is about 5,300 feet, but southwards this is reduced to less than half and in the country east of Kalar Kahar is only 2,460 feet; on both sides of the railway line between Uchhri and Chhab and between it and the Indus the thickness may be even less since the total thickness of the Middle Siwaliks does not exceed 3,500 feet. In the southeastern part of the Potwar there is an even greater thinning out, for the Middle Siwaliks in the Jalalpur-Chambal section are only 1,300 feet thick, consisting apparently exclusively of Nagri beds in the form of deep orange and reddish brown clays with grey sandstones and occasional conglomerate bands.[100] The change from the argillaceous Chinjis to the massive sandtsones of the Nagri stage is comparatively sharp, and in most cases the belt of passage beds is not more than 100 feet or so, but to the northwest of Pindigheb there are 500 feet of beds of transitional character which have been included with the Chinjis.

The massive beds of Nagri sandstone, some of them as much as 300 feet in thickness, are parted by clays or silts which, though not so brightly coloured as those in the Chinji below or the Dhok Pathan above, retain a light reddish tint in the lower horizons; this tint

[98] G. de P. Cotter, Mem. 55, 113 (1933).
[99] Mem. 55, 112-121 (1933).
[100] G. E. Pilgrim, Rec. 43, 274 (1913).

becomes slightly more orange in shade higher up in the scale. The sandstones, of a pale olive green colour, are usually medium in grain, and contain abundant scattered pebbles and sometimes "dogger" concretions; dark bands abounding in magnetite are not uncommon. True but inconstant conglomerates occur, especially at the base, but pseudo-conglomerates are more frequent. Limonitised and silicified fossil wood is of common occurrence over wide areas, but vertebrate remains are somewhat rare, ill preserved, and more or less restricted to the upper part of the stage; the lowest 1,500 feet are almost unfossiliferous in the neighbourhood of Nagri and Chinji, but from beds situated from four to four-and-a-half miles west of Hasnot in the Jhelum district and mapped as lying near the base of the Middle Siwalik, Barnum Brown has collected several fine antilopine skulls and other mammalian specimens.

The Nagri fauna, smaller than either the Chinji below or the Dhok Pathan above, shows marked indications of being intermediate in character between the two, and appears to fulfil the requirements which would render it the equivalent of the European Sarmatian; like the Dhok Pathan, it is characterised by the abundance of *Hipparion*. The following have been identified:[101]

PRIMATES.

Sivapithecus giganteus Pilg.,
Sivapithecus indicus Pilg.,
"*Dryopithecus punjabicus* Pilg.",
Dryopithecus cautleyi Br., Greg. & Hedl.,
Sugrivapithecus salmontanus Lewis.

RODENTIA.

Rhizomys sivalensis Hint.,

PROBOSCIDEA.

Stegolophodon cf. *cautleyi* (Lyd.).

CARNIVORA.

Crocuta gigantea (*Schlosser*) var. *latro* Pilg.,
Vinayakia nocturna Pilg.

PERISSODACTYLA.

Aceratherium perimense Falc. & Cautl.,
Hipparion cf. *theobaldi* Lyd.,
Macrotherium salinum F. Cooper.,
Gaindatherium browni Colb.,
Chilotherium blanfordi (Lyd.),
Chilotherium intermedium (Lyd.).

[101] Mem. 55, 114 (1933); G. E. Pilgrim, Rec. 43, 318-320 (1913); Trans. Amer. Phil. Soc., New Ser. 26 (1935).

TUBULIDENTATA.

Orycteropus browni Colb cf. *O. gaudryi*;[102] genus supposed by Colbert to have originated in N. America during the late Mesozoic or Eocene,[103]
Orycteropus pilgrimi Colb.

ARTIODACTYLA.

Anthracotherium (? ***Microbunodon***) ***silistrense*** Pentl.,
Hippohyus deterrai Lewis., (more primitive than the Dhok Pathan and Tatrot species),[104]
Conohyus indicus (Lyd.),
Conohyus sindiensis (Lyd.).
Listriodon pentapotamiae (Falc.) (genus less abundant than in the Chinji,[105]
? ***Sus hysudricus*** Falc. & Cautl.,
? ***Sus bakeri*** Pilg.,
Large giraffoid intermediate in size between ***Giraffokeryx*** and ***Hydaspitherium*** and provisionally referred by Matthew to *Vishnutherium*,
Giraffokeryx punjabiensis Pilg.,
Dorcadoxa (?) cf. *porrecticornis* (Lyd.),[106]
Tragoreas (?) *potwaricus* Pilg. (more primitive than the Pontian species of Europe and China),
Kobikeryx atavus Pilg. (horizon somewhat doubtful but probably Nagri),
Sivaceros sp. (larger than ***S. gradiens*** or ***S. vedicus***),
Selenoportax vexillarius Pilg.,
Pachyportax nagrii Pilg.,
Propotamochoerus salinus Pilg. (*Sus hysudricus* Lyd. *in part*),
Dorcabune nagrii Pilg.,
Dorcatherium majus Lyd.,
Dorcatherium minus Lyd.,
Lycaena cf. *macrosoma* (Lyd.),
Hemimeryx pusillus Lyd.,
A chalicotheroid.

REPTILIA.

Gavialis browni Mook.,[107]
Crocodilus sivalensis (found near Hasnot; stage uncertain).

Matthew thinks that *Hipparion* could not have made its appearance earlier than the Pontian, but Pilgrim places the Nagri stage in the Sarmatian (see p. 1759).

Dhok Pathan stage.—The Nagri stage is followed in a normal manner by the Dhok Pathan, a stage of deep orange and red clays and grey sandstones, with occasional bands of conglomerate. Largely and irregularly covered by recent debris, it occupies a broad tract between the Salt Range and the two domes of Khaur and Dhulian, where it forms the uppermost formation of any size in the Sohan syncline, though the Sohan river itself for some distance almost coincides with the northern edge of the outcrop. Further west the Dhok Pathan outcrop widens and extends some distance to the north of the Sohan before crossing the Indus; a small synclinal strip is seen north of the broken Dakhnir anticline. In the Sohan syncline not more than 1,000 feet of these beds are present near Dhok Pathan,

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102 Amer. Mus. Novit. No. 797, 4 (1935).
103 Amer. Mus. Novit. No. 604, 1-6 (1933).
104 Amer. Journ. Sci. Ser. 5, 27, 457-459 (1934).
105 G. E. Pilgrim, Pal. Ind., New Ser., 8, No. 4, 31-34 (1926).
106 Pal. Ind., New Ser., 26, Mem. 1, 44-47 (1939).
107 Amer. Mus. Novit., No. 514 (1932).

though there is a slight increase in thickness westwards; much of the higher horizons of this stage appears to have been removed by denudation. Along the Salt Range flank, thicknesses of 2,000 and 2,100 feet have been measured, and to the south of Tamman a maximum figure of 3,000 feet is recorded. South-eastwards there is good reason to believe that the Dhok Pathan dies out, for in the Jalalpur-Chambal section the stage appears to be entirely absent, the Middle Siwaliks being represented by 1,300 feet of beds of Nagri character.[108] At Hatar, 5 miles northwest of Jalalpur, the Middle Siwaliks have increased to 1,700 feet and at Kotal Kund, another 5 miles in the same direction, to a still larger figure; at the latter locality higher beds of a paler tint make their appearance with fossils of a Dhok Pathan type. Between the Tatrot plateau and the Tilla ridge, the Dhok Pathan fauna is found through a thickness of some 1,000 feet; the rest of the Middle Siwaliks here probably belong to the Nagri, which must be just under 3,000 feet thick.

The colour of the Dhok Pathans contrasts strongly with that of the Nagris, and their passage upwards into the Upper Siwalik of the Potwar is described by Cotter as abrupt. Their sandstones are characteristically of a gleaming or glistening white colour, while the clays, though occasionally of a brown or drab tint, are most frequently a bright orange or red. The basal bed is in many places a conglomerate which is over 100 feet thick a few miles E.S.E. of Khaur; westwards it dies out for a space but reappears west of Pindigheb, where it crops out in low ridges.

Both Cotter and Lahiri would include in the Dhok Pathan stage the well known conglomerates and boulder beds of Makhad and other parts, but their position along the central portion of the Sohan syncline, and their general character tally with their assignment to the uppermost Siwalik, where they have been hitherto placed.

The Dhok Pathan fauna, richest of all Siwalik faunas, is as follows:[109]

MOLLUSCA.

Indonaia hasnotensis Vokes.

[108] G. E. Pilgrim, Rec. 43, 275 (1913).

[109] There has in the past been a certain amount of confusion between Dhok Pathan and Tatrot species due to the following facts. Hasnot, a locality rich in fossils of Dhok Pathan age, lies less than a mile distant from a cliff which forms the boundary of the Tatrot stage. Tatrot specimens are frequently washed down on to Dhok Pathan outcrops and have in some instances been recorded as Dhok Pathan species Fortunately the character of the matrix is generally sufficient to distinguish the two sets of fossils, but where the matrix has been removed, as it has in some of the specimens belonging to old collections, there is no clue to the age, and there is a slight chance that one or two in the list given above may have been erroneously classed as Dhok Pathan when they are in reality Tatrot. The above list as well as the other fossil lists, in this section has been carefully scrutinised by Guy Pilgrim to whom the author is deeply indebted.

Primates.

Palaeopithecus sivalensis Lyd.,
Cercopithecus (?) *hasnoti* (Pilg.),
Macacus (?) *sivalensis* Lyd.

Carnivora.

Arctamphicyon lydekkeri Pilg.,
Agriotherium palaeinaicum (Lyd.) (more primitive than *A. insigne* of Montpellier),
Indarctos salmontanus Pilg. (cf. *I. atticus* from the European Pontian),
Indarctos punjabiensis (Lyd.),
Eomellivora (?) *tenebrarum* Pilg.,
Mellivora punjabiensis (Lyd.) (Pilgrim's "*Promellivora*"),
Plesiogulo brachygnathus Schloss (found in the Pontian of Shan-si, China),[110]
Sivaonyx bathygnathus Lyd. (cf. *S. hessicus* from the Pontian of Eppelsheim),
? *Enhydriodon falconeri* Pilg. (cf. *E.* (?) *laticeps* from Pikermi),
Lutrine genus indet. *hasnoti* Pilg.,
Vishnuictis salmontanus Pilg.,
Ictitherium sivalense Lyd. (cf. *I. wongi* from China),
Ictitherium indicum Pilg.,
Lycyaena macrostoma (Lyd.) (cf. *L. cheretis* from the European Pontian),
Lycyaena macrostoma, var. *vinayaki* Pilg.,
Crocuta carnifex Pilg.,
Crocuta gigantea (Schlosser) (found in the Pontian of China),
Crocuta gigantea, var. *latro* Pilg.,
Crocuta mordax Pilg. (cf. *C. eximia* and *C. variabilis* of the European and Chinese Pontian),
Aeluropsis annectans Lyd.,
Mellivorodon palaeindicus Lyd. (regarded as indeterminable by Matthew),
Propontosmilus sivalensis (Lyd.),
Paramachaerodus pilgrimi Kretzoi,[111] (cf. *P. orientalis*),
Paramachaerodus indicus (Kretzoi),
Machaerodus or *Epimachaerodus* sp.,
Felis sp.

Rodentia.

Rhizomys sivalensis Lyd.,
Hystrix sivalensis Lyd. (cf. *H. hirsutirostris*).

Proboscidea.

Dinotherium giganteum ("*D. indicum*") Falc.; final appearance of this old genus,[112]
Mastodon (*Chœrolophodon*) *corrugatus* Pilg. (cf. *M.* (*Ch.*) *penteleci* from Pikermi),
Mastodon (*Chœrolophodon*) *hasnoti* (Pilg.),
Mastodon (*Chœrolophodon*) *propathanensis* (Osb.),
Mastodon (*Trilophodon*) *browni* (Osb.),
Mastodon (*Tetralophodon*) *punjabiensis* Pilg.,
Mastodon (*Tetralophodon*) *perimensis* (Falc. & Cautl.),
Mastodon (*Tetralophodon*) *falconeri* (Lyd.),
Serridentinus chinjiensis Osb.,
Serridentinus metachinjiensis Osb.,
Stegolophodon cf. *cautleyi* (Lyd.).

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[110] Amer. Journ. Sci. Ser. 5, Vol. 26, 80 (1933).

[111] G. E. Pilgrim, Rec. 45, 138-155 (1915).

[112] G. E. Pilgrim, Rec. 43, 292 (1913).

PERISSODACTYLA.

Hipparion theobaldi Lyd., (both this species and *H. punjabiense* are less advanced than *H. crassum* of Rousillon),
Hipparion punjabiense Lyd. (according to Matthew=*H. antilopinum*),
Hipparion chisholmi Pilg. (according to Matthew=*H. antilopinum*),
Aceratherium lydekkeri Pilg.[118]
Aceratherium perimense (Lyd.),[113]
Chilotherium blanfordi (Lyd.),
Chilotherium intermedium (Lyd.).

ARTIODACTYLA.

Tetraconodon mirabilis Pilg. (locality uncertain ; a genus with enormously developed premolar teeth),
Sivachœrus prior Pilg. (found also in Pakokku),
Propotamochœrus uliginosus Pilg. (probably Dhok Pathan ; genus more primitive than *Potamochœrus*),
Propotamochœrus hysudricus (Lyd.) (abundant),
Propotamochœrus ingens Pilg.,
Listridon pentapotamiae (Genus very scarce in this stage ; a survival from the Chinji ; cf. *L. splendens*, a survival from the Tortonian).
Dicoryphochœrus titan (Lyd.) (abundant),
Dicoryphochœrus titanoides Pilg. (presumably from the Punjab),
Dicoryphochœrus vinayaki Pilg. (common),
Dicoryphochœrus vagus Pilg. (common),
Hippohyus lydekkeri Pilg.,
Sivahyus hollandi Pilg.,
Hyosus tenuis Pilg.,
Hyosus cf. *punjabiensis* (Lyd.),
Sus adolescens Pilg.,
Sus comes Pilg.,
Sus praecox Pilg.,
Sus hysudricus Falc. & Cautl.,
Sus bakeri Pilg.,
Dorcabune latidens Pilg.(=*Anthracotherium silistrense* Pentl. *in parte*),
Microbunodon silistrense (Pentl.),
Merycopotamus cf. *dissimilis* Falc. & Cautl.,
Hippopotamns irravadicus Falc. & Cautl.,
Dorcatherium majus Lyd. (this and the following species regarded by Matthew as inadequate types of no correlational value),
Dorcatherium minus Lyd.,
Hydaspitherium grande Pilg. (according to Matthew=*H. megacephalum* Lyd., cf. *Helladotherium duvernoyi*),
Vishnutherium iravadicum Lyd.,
Hydaspitherium megacephalum Lyd. (gigantic giraffid),
Hydaspitherium grande Lyd. (cf. *Helladotherium duverniyi* of the European Pontian),
Hydaspitherium magnum Pilg. (?=*H. grande* Lyd. non. Pilg. Matthew).
Giraffa punjobiensis Pilg. ("*Camelopardalis sivalensis* Lyd." *in parte ;* cf. *G. attica* from the European Pontian),
Bramatherium perimense Falc., (Colbert),
Tragocerus browni Pilg.,
Tragocerus punjabicus Pilg. (cf. *Tr. amalthea*),
Tragoportax islami Pilg. (cf. *Tr. leskewitschi* of Sebastopol),
Tragoportax salmontanus Pilg.,
Proamphibos cf. *lachrymans* Pilg. (cf. *Parabos* (?) *macedoniae*),
Proamphibos (?) *hasticornis* Pilg.,
Pachyportax latidens Lyd.,
Pachyportax latidens, var. *dhokpathanensis* Pilg.,

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[118] W. D. Matthew disagrees with this generic determination and regards the specimen as belonging to a form related to *Chilotherium*.

ARTIODACTYLA—*contd.*

Selenoportax lydekkeri Pilg.,
Selenoportax vexillarius Pilg.,
Ruticeros pugio Pilg.,
Gazella lydekkeri Pilg. (cf. *G. capricornis*; more primitive than the Astian *G. borbonica*).
Gazella (?) *superba* Pilg.,
Gazelline gen. indet. (aff. *Helicotragus*) *vinayaki* Pilg.,
Dorcadoxa porrecticornis (Lyd.),
A hippotragine,
Sivaceros vedicus Pilg.

The most frequent and characteristic genus in the Dhok Pathan is *Hipparion,* which reached its maximum development in this stage. The Hippopotamidae first make their appearance in the Dhok Pathan. The genus, *Hippopotamus,* now extinct in India, though probably only very recently, for it was in existence there in the Middle Pleistocene and perhaps much later,[114] is rare in the Dhok Pathan stage, where it first appears ; it may have evolved from an advanced anthracothere, but there is some doubt concerning its ancestry. Colbert suggests that from the same group of anthracotheres may have come *Merycopotamus* through the intermediate *Hemimeryx.*[115] The earliest true Bovinae in India and Burma make their appearance in the form of *Proamphibos* in the Dhok Pathan of the Salt Range and the Irrawadian of Burma. Of the Dhok Pathan fauna there is hardly a species in common with the Chinji fauna. The Dhok Pathan assemblage shows an influx of types characteristic of a dry grass-land ; among them abound primitive elephants, *Hipparion* and antelopes. Windborne silt at the top of the stage contains *Orycteropus,* a form which now inhabits the Kalahari and Danakil deserts of Africa.

While Pilgrim correlates the Dhok Pathan with the well known faunas of Pikermi and Samos in Greece, which are regarded as Pontian, Matthew, Lewis and Colbert favour a somewhat later age. Matthew finds the Dhok Pathan species of *Hipparion, H. theobaldi* and *H. antilopinum* more highly specialised than the Grecian forms, and the giraffes, *Bramatherium* and *Hydaspitherium* more advanced than any form in the Pikermi or Samos beds ; Matthew at the same time admits that these giraffes are much less specialised than the Upper Siwalik *Sivatherium* and *Indratherium.*[116] Other planks in the argument of the American writers are the well preserved

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[114] G. E. Pilgrim, Proc. 12th. Ind. Sci. Congr., 205 (1925).

[115] Amer. Mus. Novit., 799, 22 (1935).

[116] Bull. Amer. Mus. Nat. Hist., Vol. 56, 452 (1929) ;
The grounds for the conclusion that *Hydaspitherium* is more advanced than the Pikermi form, *Helladotherium,* appear to be somewhat slender. No male skull of the latter genus has yet been found at Pikermi, nor have we specimens of the female skulls of *Bramatherium* or *Hydaspitherium* except a young skull of *Hydaspitherium grande,* which may be that of a female and shows resemblances to the female of *Helladotherium, Giraffokeryx* of the Chinji stage may well be an ancestral type of both *Helladotherium* and *Hydaspitherium.* In any case, as pilgrim points out, nothing nearly approaching the *Sivatherines* either in size or structure occurs in the Middle Siwalik assemblage.

specimen of *Plesiogulo* found a little north of Bhandar in the Pind Dadan Khan *tehsil* of Jhelum, and the specimens of *Indarctos.* In North America the genus *Pelsiogulo* is restricted to the Edson, Mt. Eden and Hemphill beds, which are looked upon as post-Pontian and correlated with the Montpellier and Rousillon of Europe.[117] *Indarctos,* a genus not found outside the Dhok Pathan beds in India, is confined in North America to the Rattlesnake formation. Against this argument, Pilgrim remarks that *Plesiogulo* is found as the same species, *P. brachygnathus,* in the Pontian beds of China, while *Indarctos* is an abundant and widely spread genus in the Pontian of both Europe and China, the species *I. atticus* being indistinguishable from the Dhok Pathan *I. salmontanus* on the material available. As both *Plesiogulo* and *Indarctos* are probably migrants into North America, it would not be surprising that their occurrence in that continent should be rather later than in the Old World.

A. T. Hopwood finds that the Proboscid fauna of the Dhok Pathan fits best in the Pontian. He remarks that *Chœrolophodon,* which had quietly evolved throughout the Kamlial and Chinji, suddenly became a dominant form in the Dhok Pathan, of which it is the dominant form in the Dhok Pathan, of which it is the commonest proboscidean fossil ; the same genus appears with the same suddenness in the Pontian of Pikermi, and Samos in Europe and of Maragha in Persia, where incidentally and curiously enough the *Chœrolophodon* remains appear to be nearly all of immature animals.[118]

As Professor Davies remarks, the *Hipparion* fauna of the Pontian is one of the richest and widest spread of fossil mammalian faunas, and has been recognised in Spain, southwest France, central Germany, the Vienna basin and Hungary, Macedonia, Turkey, Greece, the Isle of Samos, north Africa, western Persia, the Siwalik hills of India, China and the Malaya regions ; in all these countries it is usually accepted simply as Pontian, but a fauna of this kind is known in the Upper Sarmatian of Turkey and southern Russia.[119]

The name Bhandar was given to the uppermost 500 feet of the Middle Siwaliks of the southeastern Potwar, lying below an extremely hard basal Upper Siwalik conglomerate ; these beds have since yielded large numbers of fossils, collected by Barnum Brown from a bone bed near Bhandar village and are now included as part of the Dhok Pathan.

THE UPPER SIWALIK.

With their typical genera, the Upper Siwaliks can be traced generally from the Salt Range, through the Pabbi Hills, into Jammu and Kangra, and thence along the foot-hills of the Simla Hill States to the Siwalik Hills below Dehra Dun.

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[117] G. E. Lewis, Amer. Journ. Sci. Ser. 5, Vol. 33, 199 (1937).

[118] The whole question has been recently reviewed in full by Pilgrim and Hopwood ; Rec. 73, 437-482 (1938) ; Geol. Mag. 77, 1-27 (1940).

[119] A Morley Davies, "Tertiary Faunas", Vol. 2, 201 (1934).

Tatrot stage.—Of the Upper Siwalik the lowest or Tatrot stage commences to be seen to the north of the Salt Range, northeast of Kalar Karar, whence its outcrop stretches eastwards through the long, narrow, E.-W. synclinal basin of Bhaun into the country northwest of the Bakrala ridge in Jhelum. The stage consists of 2,000 feet of friable, brown sandstones, with interbedded drab and pale brown clays and conglomerates.[120] The basal bed, south of Bhaun, is a hard, brown, pebbly sandstone grading to a conglomerate and overlain by soft brown sandstone with abundant pebbles and interbedded brown and drab clays. North of Dhok Talian, this conglomerate, about 100 feet thick and resting on the Dhok Pathan beds is made up of boulders and pebbles of the size of a tennis ball, some of them composed of a pink graphic granite recalling the granite of Jalor and of neighbouring parts of Rajputana. Cotter remarks that this rock can be matched among the Talchir boulders of the Salt Range, from which it is more than probable that the Tatrot pebbles were derived. Such a conclusion fits in with the supposition that the Salt Range was an elevated tract undergoing denudation at the commencement of the Upper Siwalik epoch. The Tatrot sandstones vary in colour from cream to buff or brown, and are distinguishable from the glistening white sandstones of the Dhok Pathans below. The interbedded clay is brown, like that of the older alluvium above, but unlike the latter, is associated with subordinate beds of buff or pink sandstone and has an appreciable dip.

In the eastern portion of the Potwar, in the valley of the Bunnah river west of Mount Tilla, outcrops of the Tatrot occur at both Tatrot and Kotal Kund ; in both localities they are underlain by Dhok Pathan beds.

Beds similar to the Tatrots of Bhaun are seen on the south side of the Salt Range at Jalalpur Sharif in the Jhelum district. Some banded clays overlying the Dhok Pathan sandstones and conglomerates southeast of Uchhri railway station also show resemblances to the Upper Siwalik clays of Bhaun.

In the case of Upper Siwalik faunas there is unfortunately a strong element of uncertainty as to the precise zone from which many described specimens have been obtained. The list of forms given by Pilgrim as coming from the Tatrot stage is based entirely on collections from the lowest beds of the Upper Siwaliks of Tatrot, Kotal Kund, Bhaun and other places in the Salt Range ; at Kotal Kund this stage is 1,500 feet thick and has yielded many fossils. From the various Potwar localities the following have been collected:

LAMELLIBRANCHIATA.

Lamellidens lewisi Vokes,
Pareyssia tatrotensis Vokes,

RODENTIA.

Protachyoryctes tatroti Hint.[121] ; genus now confined to Africa.

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[120] G. de P. Cotter, Mem. 55, 121 (1933).
[121] Ann. Mag. Nat. Hist., Ser. 10, Vol. 12, 620 (1933).

CARNIVORA.

***Enhydriodon* cf. *falconeri* Pilg. (horizon doubtful, possibly Dhok Pathan).**

PROBOSCIDEA.

***Mastodon sivalensis* Falc.,**
***Stegodon clifti* Falc.,**
***Stegodon bombifrons* Falc. & Cautl.,**
Elephas (*Archidiscodon*) cf. *planifrons*,
Pentalophodon falconeri (provenance doubtful).

PERISSODACTYLA.

***Hipparion* sp.,**
Equus sp. (identified by Dr. Lewis).

ARTIODACTYLA.

***Potamochoerus palaeindicus* Pilg.,**
***Sivachoerus* cf. *giganteus* (Falc. & Cautl.),**
? *Dicoryphochœrus titanoides* Pilg. (a Dhok Pathan form possibly reaching up into the Tatrot),
? *Dicoryphochœrus vagus* Pilg. (a Dhok Pathan form),
? *Dicoryphochœrus vagus*, var.,
***Hippohyus grandis* Pilg. (largest species known; a Dhok Pathan form),**
***Hippohyus* (?) *tatroti* Pilg. (probably Tatrot),**
Hippohyus lydekkeri Pilg. (a Dhok Pathan form),
***Sus peregrinus* Pilg.,**
Hippopotamus sp.,
***Merycopotamus* cf. *dissimilis* Falc. & Cautl. (Dhok Pathan and Pinjor form),**
Sivatherium giganteum Falc. (from Makhad and Jalalpur as well as the Siwalik Hills),
***Selenoportax lydekkeri* Pilg. (Dhok Pathan form),**
***Pachyportax latidens*, var. Pilg. (Dhok Pathan form),**
***Sivaonyx bathygnathus* Pilg. (Dhok Pathan form),**
***Dorcatherium* sp.,**
Anthracotherium (*Microbunodon*) *silistrense* Pentl. (from Kakrala, 1½ miles E. of Tatrot, and possibly belonging to the Dhok Pathan stage),
Antilope cf. *planicornis*,
Sivatragus (?) *brevicornis* Pilg. (an ancestral form of the Pinjor, *S. bohlini*),
***Hydaspicobus auritus* Pilg. (ancestral to a Pinjor species),**
***Reduncine genus* (cf. *Indoredunca*) *theobaldi* Pilg.,**
***Reduncine genus* (cf. *Sivadenota*) *sepulta* Pilg.,**
Proamphibos lachrymans Pilg.

The Tatrot fauna is a meagre one and, if we except the Bovinae, is not of such a character as to invite comparison with any European fauna. Matthew and Colbert have referred it to the Villafranchian of the Val d'Arno, Perrier and Seneze, partly, we may presume, on account of the first appearance of *Equus* and of a primitive elephant, and Lewis considers it inseparable from that of the Pinjor stage. A study of these two Upper Siwalik faunas and especially of their Bovidae, has induced Pilgrim to correlate the Tatrot fauna with that of Montpellier, generally regarded as Astian, and to place it a stage further down the stratigraphical scale than that of the Pinjor. Rolled fragments of *Hipparion* occur in the basal Tatrot conglomerate, which is believed by both Pilgrim and the American writers to mark a longer inter-stage break than usual, but Pilgrim has found unrolled

fragments of this genus in beds which he claims cannot be earlier than Tatrot. This is not surprising, since the comparatively frequent occurrence of the genus in the Siwalik hills leads one to infer that it persisted into the Pinjor stage.

In spite of the conglomerate, the faunal break at the top of the Middle Siwalik is not excessive and an appreciable proportion of species pass up from the Dhok Pathan into the Tatrot, though it must be admitted that the provenance of some of these supposed common forms requires confirmation. The most characteristic Tatrot form is the primitive buffalo, *Proamphibos,* of which the females are hornless; it is represented in the Potwar by the species *P. lachrymans* and in Jammu by *P. kashmiricus.* This genus is closely allied to *Parabos* of Montpellier, and is replaced in the Pinjor by *Hemibos*; the latter, as well as other advanced bubalines *Leptobos,* and the primitive Taurina common in the Pinjor, is absent from the Tatrot fauna. *Sivatherium, Equus* and *Elephas* make their first appearance, though they are scarce in comparison with their abundance in the Pinjor assemblage. *Hipparion* and *Stegodon* are the most frequent equid and proboscid genera, respectively, in the Tatrot fauna. The leap into prominence of *Hippohyus* and *Hippopotamus* is striking, particularly in the case of the latter, which is scarce in the Dhok Pathan stage. *Merycopotamus,* the most progressive member of the *Anthracotheriidae,* comes up from the Dhok Pathan but survives into the Pinjor. *Sus* is present as a generalised species—*Sus peregrinus*— but other branches of the Suidae are represented by forms of *Dicoryphochœrus, Propotamochœrus* and *Sivachœrus.* Hippotragine and reduncine antelopes, as well as the genus *Antilope,* occur as species which are in a more primitive stage of development than their Pinjor relatives. The late Pliocene fauna from Sze-chuan in China has closer affinities with that of Malaya rather than that of India, in spite of the abundance of *Stegodon,* and has nothing in common with North America; in both the Chinese area and Malaysia are found a gibbon-like ape and a tapir.

In the Jalalpur-Chambal section, the Tatrot and Pinjor stages appear to be represented by 4,000 feet of friable brown sandstones with interbedded drab or pale brown clays and conglomerate bands, intervening between beds of Middle Siwalik age and the Boulder Conglomerate.[122] These presumed Tatrot-Pinjor beds, for the most part unfossiliferous, lie upon beds believed to be of Nagri age; there is an abrupt change from one succession to the other, the time break between the two corresponding to the whole of the Dhok Pathan. The basal portion of this Tatrot-Pinjor sequence has yielded a mandible of *Sivachœrus* cf. *giganteus,* while from 3,000 feet higher up and therefore from beds probably of Pinjor age comes *Elephas (Archidiscodon) planifrons.*

Pinjor stage.—The Pinjor stage is typically developed in the sub-Himalaya, as we shall see, and very little is accurately known of its

[122] G. E. Pilgrim, Rec. 43, 274 (1913).

occurrence. Its distinction from the Tatrot is doubted by some but, although the two are not found together in their typical fossiliferous facies, Pilgrim considers that the Tatrot is an older stage than the Pinjor (see p. 1781). In the Potwar and Salt Range region, our acquaintance with the Pinjor is confined to finds of *Elephas* (*Archidiscodon*) *planifrons* Falc. & Cautl. at various places form 2,000 to 3,000 feet above the top of the Middle Siwaliks, and of the same proboscid as well as of *Leptobos* and the horn of a large *Cervus* some 2,000 feet below the Boulder conglomerates.[123] Numerous specimens of *Dicoryphochœrus durandi* Pilg. are recorded from the Pinjor stage of the Salt Range which, at Jharakki has also yielded *Sivafelis potens* Pilg. From the eastern portion of the Sohan valley specimens belonging to the Dhok Pathan stage have been collected, but whether the Tatrot and Pinjor stages are also present, or whether the Boulder Conglomerate stage lies directly and unconformably upon the Dhok Pathan is not yet certainly known. In the eastern Potwar, according to Wadia, the Pinjor horizon is not definitely separable, but is presumed by him to underlie the Boulder Conglomerate stage in the country intervening between the valleys of the Jhelum and Sohan.

In the Campbellpur basin, north of the Kala Chitta, a fluvio-glacial gravel is recorded by De Terra and De Chardin lying upon gently folded orange clays and whitish-grey sandstones, at the base of which was found a palate of *Equus* and a bone pocket including remains of *Stegodon*, *Bubalus*, deer, *Hyaena*, *Felis*, *Machairodus*, *Mustela*, *Viverra*, *Boselaphus*, a strepsicerine antelope, and *Sus*. Higher up are brown clays with indistinct plant remains, interbedded with pinkish or grey silts and partly cross-bedded sandstones. These beds, some 500 feet thick, are described as forming a flat anticline unconformably overlain by the Boulder Conglomerate; they appear to be of Pinjor age.[124]

Boulder Conglomerate.—The uppermost stage of the Siwaliks, the Boulder Conglomerate, is widely developed along the more central part of the Potwar plateau, a large area of which is covered by the disintegrated boulders therefrom. When loosely compacted it is with difficulty distinguished from its own debris. The pebbles in these beds, ranging up to 18 inches in diameter, are made up very largely of metamorphic and igneous rocks of an exteremely varied assemblage,[125] a small percentage being of limestone including the nummulitic variety. The beds of conglomerate are inconstant and have intercalations of soft, grey sand-rock and orange clay. Attempts have been made to distinguish between this uppermost Siwalik stage and practically undisturbed gravels, conglomerates and boulder beds of supposedly later date, but the dip of such deposits, lying as they do in a geo-syncline which has been and probably still is affected

[123] G. E. Pilgrim, Rec. 43, 323 (1913).

[124] Proc. Amer. Phil. Soc., Vol. 76, 796-797 (1936).

[125] A. B. Wynne, Rec. 10, 121, footnote (1877).

by a strong and continuous folding movement, is a somewhat unreliable factor and appears to depend more upon distance from lines of maximum flexure and thrusting. In this way dips are more likely to be steep in the vicinity of the Kala Chitta and Margala hills than they are further south. In the Sohan valley, wherever it is possible to make out a dip in the rocks of this stage, it is usually very gentle, and conglomerate beds can be seen lying unconformably in places on the older Siwalik stages. On the other hand, near Golra village, just below the Margala range, a band of conglomerate, almost certainly of Pleistocene age and lying unconformably upon denuded Eocene beds, has been tilted to a vertical position.[126] The question as to where the upper boundary of the Siwalik series should be drawn is obviously a matter of convention, the most suitable perhaps being that particular level which marks the replacement of the Great Siwalik river by the comparatively insignificant Sohan. Even in that case the distinction will remain of an artificial kind, for the gravels and silts laid down in the Potwar and other parts of the old Siwalik river valley today are in all respects but a continuation on a smaller scale of the Siwalik sedimentation which has never everywhere and simultaneously ceased. Unfortunately, there is very little fossil evidence on which to date the conglomerates of the Potwar and Salt Range.

At Makhad, on the Indus, these conglomerates are some 2,000 feet thick and practically horizontal. Cotter and Lahiri claim that, on passing westwards from Dhok Talian on the north side of the Salt Range above Pind Dadan Khan, the white Dhok Pathan sandstones can be seen giving place laterally to thick conglomerates, which are well exposed north of Tamman, near Trap and Makhad, and further north on the other side of the Sohan, to the east of Chhab. According to these observers, who appear to have found difficulty in identifying the Boulder Conglomerate stage as such in the western parts at least of the Potwar and in the Attock district generally, much of the conglomeratic material of this region hitherto regarded as belonging to the uppermost stage of the Siwalik, is but a local facies of the Dhok Pathan stage. Mr. Anderson, who also finds it difficult to distinguish with any certainty between the Middle and Upper Siwaliks, notes the lateral passage of " thick zones of siltstone or sandstone, which locally might be taken to have almost formational importance, into coarse conglomerate, or *vice versa* ".[127] On the other hand, their position along the central portion of the Sohan syncline and the justifiable expectation that they should be found here completing the Siwalik sequence as they do in the sub-Himalaya, tally with their assignment to the top of the Upper Siwalik where they have hitherto been placed. In the neighbourhood of Makhad, the conglomerates, which include pebbles up to four inches in diameter, composed of hornblende gneiss and quartzite, are interbedded with coarse sandstone containing plates of muscovite.[128] The

[126] E. H. Pascoe, Mem. 40, 393 (1920).
[127] Bull. Geol. Soc. Amer. 38, 688 (1927).
[128] G. de P. Cotter., Mem. 55, 117 (1933).

palæontological evidence in favour of an Upper Siwalik age for these beds is admittedly not very satisfactory and is based on a metatarsal identified as belonging to the Upper Siwalik genus, *Sivatherium*. Cotter finds it impossible to distinguish this bone from a metatarsal of *Hydaspitherium*, and also points out that *Sivatherium* itself may extend down into the Dhok Pathan stage.

Pinfold applies the term Upper Siwalik to the conglomerates of the Potwar but concludes that they overlap many of the older rocks and are possibly continuous with the recent conglomerates of the alluvium and with the river gravels.[129] The question requires clarification but the chances are that the uppermost Siwalik stage will be found to be represented here and there within this tract. Both the older conglomerates and to a smaller extent the Recent alluvium have, in certain places, more especially in the close neighbourhood of the so-called boundary fault, been affected by earth movement. One of the best instances, recorded by Mr. Pinfold as well as the writer, is at Golra a few miles northwest of Rawalpindi, where a conglomerate bed of limestone boulders is seen dipping vertically and in unconformable contact with Eocene beds;[130] this locality is within 1½ miles of the major thrust trace in the Margala hills. Whatever the age of these clastic deposits may be, they include pebbles of Triassic, Jurassic and Eocene rocks, derived in all probability from northern regions, as well as of *Alveolina* limestone and Murree sandstone from neighbouring sources.[131]

In the eastern Potwar Wadia records the presence of the Boulder Conglomerate beds, from 2,000 to 3,000 feet thick, spreading in shallow rolling synclines on both sides of the lower portion of the Jhelum.[132] The crude wide-spaced stratification planes of these deposits are described as producing no appreciable effect upon the topography which is an undulating succession of rounded knolls or mounds. On the right bank of the Jhelum, E.S.E. of Rawalpindi, the Boulder Conglomerate, nearly 3,000 feet in thickness, is made up of pebbles, from 6 to 15 inches across, of compact siliceous rocks in a scanty sandy matrix. In the eastern Potwar generally the conglomerate stage is unfossiliferous for long distances, but limb bones and fragments of incisors of *Elephas* have been collected. In the extreme southeastern angle of the Potwar, between Jalalpur and the Chambal ridge, the Upper Siwaliks include 1,000-2,000 feet of Boulder conglomerates, with *Elephas hysudricus*. *Sivatherium giganteum* Falc., *Cervus* aff. *duvaucelli*, *Equus*, *Bos*, *Camelus* and *Dicerorhinus platyrhinus*; these beds are overlain by the loosely compacted

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[129] Rec. 49, 156 (1918); The conglomerates near Injra mentioned by this observer as forming part of the upper Siwalik are those which Cotter and Lahiri regard as belonging to the Dhok Pathan.

[130] E. H. Pascoe, Mem. 40, 396, fig. 5 (1920).

[131] A. B. Wynne, Rec. 10, 121 (1877).

[132] Mem. 51, 285-286 (1928).

sands of Rasul which may be classified as uppermost Siwalik since they have yielded *Stegodon ganesa*.[133]

Punch and Gujrat district.—The Palandri and Mang stages of Punch have already been discussed since the latter has yielded a fossil not found above the Murrees. The classification of the Siwaliks in this State needs revision, and there appears reason to suspect that the various stages defined are of greater age than they were at first supposed to be. Thus, if *Aceratherium bugtiense*, a form not easily mistaken on account of its great size, has been rightly identified, some if not all the beds referred to the Lower Siwalik must belong to the Murree (Gaj). Whatever their precise age, the Upper Tertiary beds of this area are characterised by rapid weathering resulting in strikingly abrupt escarpments and dip slopes. The strata are described as highly inclined and often vertical.

The Mang stage is described as in some places passing up conformably into the comparatively thin Helan stage which was tentatively correlated with the basal Nagri but which might, from its description, belong for the most part to the Kamlials. For one thing, it is not more than 1,500 feet in aggregate thickness and forms synclinal hill-crests with well cut mural escarpments of considerable elevation. It is made up of soft, coarse, massive sandstone with inconspicuous clays and shales, underlain by a rather prominent zone of deep red calcareous shales and nodular clays. In several localities the Helan stage is said to transgress rapidly over the Mang on to the Palandri and even on to the rocks below.[134] The only fossils, in addition to numerous plant impressions in one of the shale bands, are a few fragmentary limb bones of perissodactyl ungulates and remains of a small species of *Dinotherium*.

The Upper Siwalik Boulder Conglomerate occurs in some small outliers at Kotli, and its former presence over a larger portion of this terrain is proved by the copious gravel debris. As Wadia graphically remarks, " the gigantic escarpments visible in the hills bordering the Jhelum on either side and the enormous mounds of residual gravel left in the intervening hollows, furnish us with a quantitative measure of the sub-aerial waste that has taken place during the period of their exposure ".[135]

With their typical genera, the Upper Siwaliks can be traced generally from the Salt Range through the Pabbi Hills into Jammu and Kangra and the Siwalik hills of Hoshiarpur and Dehra Dun.

Jammu and Gurdaspur.—Of the Siwalik beds in the State of Jammu and the district of Gurdaspur there is as yet little detailed information, which is unfortunate since the section promises to be critical one and may provide some much needed evidence regarding the correlation of the Potwar with the Siwalik hills area and the connecting up of the various stages from the Chinji to the Boulder

[133] G. E. Pilgrim, Rec. 43, 274 (1913).
[134] D. N. Wadia, Mem. 51, 277 (1928).
[135] Mem. 51, 279 (1928).

Conglomerate. From a Chinji horizon at Ramnagar in Jammu come *Sivapithecus middlemissi* Pilg., *Dryopithecus pilgrimi* Br. Greg. & Hellm.. ad a horn-core of *Helicoportax tragelaphoides* (Barnum Brown), while from the base of the Jammu hills has been collected the Middle Siwalik giraffoid, *Hydaspitherium megacephalum* Lyd. *Tetracondon mirabilis* Pilg., recorded from Jammu, is probably from a Dhok Pathan horizon.

The section along the Tawi river, between Nagrota and Jammu city, has been described by de Terra and de Chardin, and referred to by Das Hazra.[136] The first two authors speak of the Middle Siwaliks, dipping at a comparatively steep angle, succeeded by variegated clays and sandstones of typical Dhok Pathan facies, the junction being slightly unconformable. According to Das Hazra, the Dhok Pathan is not seen in the Tawi section, though present further north, and is most probably overlapped by the Upper Siwaliks which here lie directly upon Nagri beds. The Upper Siwalik, about 2,200 feet thick, comprises basal conglomerates and brown to pink clay with fresh-water shells, followed by alternating pink, yellow and grey silts with sandstone layers and brown clay, among which a bone-bearing sandstone yielded teeth of *Equus, Bos,* and *Elephas planifrons*. With an ever decreasing dip these beds are succeeded by 1,800 feet of pink and yellow clay, alternating with conglomerate layers, and finally by a conglomerate or loose bouldery gravel which builds up the conspicuous ridge on which Jammu stands, with a dip of 5-10° towards the plains. The boulders, lying in a reddish matrix of sand and silt, are either of quartzite or less frequently of igneous rocks, and are said to display, in some cases, facetting and other signs of glacial smoothing and polishing. In the Upper Tawi valley, the coarse and massive Boulder Conglomerate of the Siwalik series is described by Medlicott as nearly vertical, including blocks as large as two feet in diameter, made up almost exclusively of Tertiary sandstone.[137] From rocks probably not older than Upper Siwalik at Nagrota and equivalent to the beds with fresh-water shells mentioned by de Terra and Chardin, come the unionid, *Lamellidens jammuensis* Prash. and *Indonaia mittali* Prash.; from the Upper Siwaliks of Khanpur has been identified *Pareyssia* sp.[138]

In the neighbourhood of Udhampur, some 15 miles further north, the Murrees pass up into the Kamlial, the base of which has been taken by Das Hazra to be an invariably present ossiferous clay conglomerate. A similar bed also demarcates the top of the stage.[139] As in the Potwar the Chinjis are essentially an argillaceous formation, the proportion of clay to sand being 2:1 near the base and 1:1 near the top. The beds of this stage are composed of the usual red clays, soft, light-coloured sandstones and pseudo-conglomerates; from them Aiyengar has collected *Conohyus chinjiensis* Pilg.,

[136] Proc. Amer. Phil. Soc. 76, 802-803 (1936); Gen. Rep. Rec. 73, 94 (1938).
[137] Rec. 9, 53 (1876).
[138] B. Prashad, Rec. 60, 308-312 (1927).
[139] Gen. Rep. Rec. 73, 93-94 (1938).

Chœromeryx sp., *Rhinoceros* sp., a giraffe and the fish, *Arius*. The Chinjis are gradually succeeded by over 6,000 feet of coarse, massive pepper-and-salt sandstones and inconspicuous grey clays belonging to the Nagri. Local calcification of the sandstones produce on weathering characteristic balls of various size and shape. In the Jammu-Udhampur road section the Nagri beds are conformably succeeded by the Dhok Pathan stage, and it is probably the latter which has yielded *Hydaspitherium* cf. *megacephalum* Lyd., *Tetracondon mirabilis*, and *Merycopotamus*. Here also the Dhok Pathan is succeeded by the Pinjor with *Hippopotamus sivalensis* Falc. & Cautl. *Stegodon* sp. and *Elephas*,[140] and the Boulder Conglomerate. The former rock stage is composed of coarse, crumbling, pebbly sandrock and variegated silts and clays, while the latter consists of boulder conglomerates with a meagre sandy matrix.[141] De Terra and de Chardin note that the Upper Siwaliks of this area, made up of a thick series of grey conglomerates, sandstone and silt, are faulted against steeply folded Lower and Middle Siwaliks.

Aiyengar has collected a skull identified as *Proamphibos kashmiricus* Pilg. near Parmandal, in the Samba *tahsil*, from beds which he assigns to the base of the Upper Siwaliks. This would imply a Tatrot age, although the species is somewhat more progressive than *Proamphibos lachrymans* from the Potwar. From the Dhok Pathan stage of Athem the same authority has collected *Tragoportax aiyengari Pilg*. Lying with a pronounced unconformity upon the denuded edges of the Upper Siwalik, Nagri, Chinji and Murree deposits, of this region, is a bouldery gravel or conglomerate, a few hundred feet thick, which is best regarded as post-Siwalik in age. This deposit, composed mainly of sub-angular boulders of Murree sandstone in a reddish sandy matrix, when traced up the Tawi valley merges into a ground moraine (belonging to de Terra's "second" ice advance).

Wadia estimates that the Upper Siwalik of Jammu may be as much as 10,000 feet thick or more in places, unless the specimen of *Stegodon ganesa* discovered by him can have come from earlier beds;[142] this specimen was found about six miles north of Jammu town in beds which are in all probability not older than the base of the Pinjor, and is remarkable for a tusk over 10 feet in length.[143] Another probably Pinjor fossil found near Jammu town is *Crocuta sivalensis* (Falc. & Cautl.); another Upper Siwalik form from Jammu State is *Buffelus palaeindicus* Falc.

In the Nar-Budhan area two anticlinal flexures have exposed 3,300 feet of Lower Siwaliks without their base being seen; they consist of soft sandstones with layers of scattered foreign pebbles, prominent brick-red shales and harder pseudo-conglomerates, the last being especially well developed at the crests of the domes. The upper

[140] Gen. Rep. Rec. 72, 19 (1937).

[141] Gen. Rep. Rec. 73, 94 (1938).

[142] Rec. 56, 352-355 (1924).

[143] Gen. Rep. Rec. 58, 19 (1925).

portion of these beds is described by Middlemiss as identical with the Chinji beds and as followed downwards by beds extremely like the Kamlials,[144] and like them forming steep scraps. Above the Lower Siwaliks come about 4,000 feet of soft sandstones, weathering in massive mural cliffs and pale-coloured shales, representing the Middle Siwaliks; from them have been collected a molar tooth of *Mastodon*—probably *M. latidens*— and some fragmentary indeterminate bones. The Upper Siwaliks which follow must be over 5,000 feet, since the total thickness of the Siwaliks of this region is estimated by Middlemiss at 12,400 feet.

Pabbi Hills.—Seven or eight miles south of the river Jhelum and the cantonment of that name is the low, barren and rugged chain of the Pabbi or Khareean hills in the Gujrat district of the Punjab, stretching E.N.E. 'wards from the vicinity of the battlefield of Chilianwala for about 28 miles. This anticlinal range is composed entirely of Upper Siwalik beds of which the upper 1,000-2,000 feet belong possibly to the Conglomerate stage and have yielded *Stegodon ganesa* Falc. & Cautl., *Elephas hysudricus* Falc. & Cautl., *Hemibos triquetricornis, Dicerorhinus platyrhinus* Falc. & Cautl. and *Buffelus platyceros* Lyd. The underlying beds, from which a species of *Stegodon* the only fossil so far recorded, are lithologically of the same appearance as the Tatrot beds of Bhaun and Dhok Talian,[145] but have been assigned by Pilgrim to the Pinjor;[146] their base is not exposed.

From these beds de Terra and de Chardin have collected *Stegodon insignis,* Falc. & Cautl., *Elephas* (*Archidiscodon*) *planifrons* Falc. & Cautl., *Coelodonta platyrhinus* (Falc. & Cautl.), *Rhinoceros sivalensis* Falc. & Cautl., *Sus falconeri* Lyd., *Hippopotamus* (*Hexaprotodon*) *sivalensis* Falc. & Cautl., *Cervus sivalensis* Lyd., *Sivatherium giganteum* Falc. & Cautl., *Taurotragus latidens* (*Lyd.*), *Bos acutifrons* Lyd., and *Antelopine* horn core.[147]

THE SIWALIK HILLS, (KANGRA, HOSHIARPUR, AMBALA, THE SIMLA HILLS STATES INCLUDING BILASPUR, DEHRA DUN, GARHWAL, NAINI TAL AND NEPAL).

Distribution, mode of occurrence and structure.—The name Siwalik, originally applied to the range of the hills stretching from the Ganges to the Jammu and separating the *dun* known as Dehra Dun from the plains, has been extended by geographers, north-westwards as far as the Beas river and south-eastwards to a little beyond longitude 82° E. in Nepal, to the hills fringing the southern foot of the Himalaya and having a geographical individuality apart from the latter. This belt of hills, several miles wide, is made up of a series of parallel ridges, most of them with a steep scarp facing south and a gentler dip slope on the north side. In spite of local variations

[144] Rec. 49, 200 (1918).
[145] G. de P. Cotter, Mem. 55, 122 (1933).
[146] Rec. 43, 274-276 (1913).
[147] Proc. Amer. Phil. Soc., 76, 806, 808 (1936).

in texture, inevitable from their mode of formation, the upper Tertiary beds occupying these hills and known by the same name maintain the already remarked uniformity of type along the whole length of the Himalayan range up to its termination in upper Assam, wherever they have escaped concealment beneath the more recent alluvial deposits of the Ganges and Brahmaputra.

The rocks of fluviatile origin exposed in the hills around and below Nahan were originally considered to be the oldest portion of the Siwalik series and were designated sometimes as "Lower Siwaliks", sometimes as the "Nahan group".[148] The term "Middle Siwalik"—the "Sand Rock stage" of Middlemiss[149]—was applied to the lower portion of the beds of the Siwalik range and the term "Upper Siwaliks" was given to the coarse conglomerates which occupy the upper portion of the sequence in these hills. Occasionally the name "Siwaliks" has been used exclusively for that portion of the series exposed in the Siwalik hills, as opposed to "Nahans" for the older Siwaliks. The Upper Siwalik division of Pilgrim's classification and nomenclature, which are now universally accepted, includes both the original Middle and Upper Siwaliks, while his Middle Siwalik division is held to apply to an older part of the series than is exposed in any section of the Siwalik range proper. Pilgrim's scheme is based on the river deposits of the Potwar; his middle Siwaliks are represented in higher parts of the sub-Himalaya although absent in the ranges spoken of as the Siwalik Hills. The term Nahan may be retained as a local designation for the Lower Siwalik beds found along this sub-Himalayan belt.

Where the succession is uninterrupted, as for example near Nalagarh, the beds of the Dagshai-Kasauli or Murree series in all probability pass up conformably into the Nahans, the general purple colour of the former changing gradually to the prevailing grey ("Pepper-and-salt") of the softer Nahan sandstones, through a succession of passage beds which, if not part of the Kasauli group, may represent the Kamlial stage; these intermediate beds contain fossil palm wood and a variety of *Mastodon* (*Trilophodon*) *angustidens* older than the Chinji form.[150]

At Kundlu further north, and at many other localities these fossil wood beds are absent and strata which are in stratigraphical continuity with a Chinji horizon at Hari Talyangar in Bilaspur are found resting on the Dagshais with an unconformity which is described as the most striking discordance in the whole sequence of fresh-water deposits and evidently representing a period of considerable earth movement.

Throughout a large part of the region under consideration the Dagshai-Kasauli and the Nahan groups are found in distinct areas separated by a marked structural feature, exhibiting itself at the pre-

[148] H. B. Medlicott and W. T. Blanford, Man. 1st. Edit, pt. 2, 524 (1879).
[149] Mem. 24, 18-30 (1890).
[150] Gen. Rep. Rec. 55, 41 (1923).

sent day as a fault of many thousand feet throw, commonly spoken of as the Main Boundary Fault. The lithology of the Nahans, however, resembles closely that of the older Dagshai-Kasauli group, and this resemblance, exemplified especially in the case of the clays and siltstones, is no doubt due to similarity in conditions of deposition. It is quite possible that much of the sequence mapped as the lowest part of the Nahan group is equivalent to some portion of the Kasauli. The great thickness of the Nahan arouses the suspicion that the group as defined ranges down into horizons lower than the Kamlial. In places the Nahan beds have been described as shading into the Kasaulis.

Speaking generally, the rocks of the Siwalik hills and their extension consist in their lower portion of a great thickness of fine-grained, micaceous, pepper-and-salt sandstone with interbedded clay bands in the lower horizons; the higher part of the series is composed of coarse conglomerates containing well rounded pebbles and boulders of crystalline and metamorphic rocks derived from the higher Himalayan ranges, and soft earthy clays indistinguishable from the alluvium of the plains except for the disturbance which they have undergone.

In the Nahan area the boundary between the Nahan group and the rest of the Siwalik series is a large strike fault which persists for some distance in a southeasterly direction, the distinction between the Nahan and the higher Siwalik beds being well maintained as far as the Nepal frontier; north-westwards the Nahan is not so easily separable and all three divisions of the series can be recognised, though the succession has been disturbed by several large strike faults. East of Hoshiarpur to take an exemplary section—the Siwaliks occupy low, parallel N.W.-S.E. hill ranges separated from each other by wide valleys.[151] The most prominent of these ridges is the Solasinghi or Chaumukhi, which with the adjoining and shorter Naina Devi ridge forms a much folded anticlinorium;[152] the Solasinghi itself is occupied by a highly compressed anticlinal structure exposing the Lower Siwalik or Nahan, the crest of the ridge being formed of Nahan (Nalagarh) sandstone. This anticline is broken by a prominent strike fault—the Budsur (Barsar) fault—which runs along the northeastern foot of the ridge, and has been traced as far as the Beas. On the northeastern side of the fault is a syncline of Pinjor rocks, also broken by a long strike fault. Further northeast, Middle Siwaliks are overthrust on to the Pinjor beds along the Gumber fault which, unlike the others, follows a markedly zig-zag course. On the southwest side of the Solasinghi ridge come almost vertical Pinjor beds, then another strike fault—the Kesori fault—separating the Pinjors from a syncline of Middle Siwaliks containing an outlier of the Pinjors, followed on the southwest by an asymmetrical anticline which is on the same tectonic line as the Naina Devi flexure.

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[151] Gen. Rep. Rec. 67, 56 (1933).
[152] Gen. Rep. Rec. 41, 84 (1911).

Of the Naina Devi ridge, which is adjacent to part of the longer Solasinghi range on its southwest side and occupies the great bend made by the Sutlej in Bilaspur, the northeastern slope is formed of the Nahan and the southwestern of the Dagshai, the dip of the rocks being generally to the northeast.[153] Along the southwestern foot of the ridge a large fault—the so-called "Boundary Fault" already mentioned—separates the purple Dagshai-Kasauli series from the Upper Siwaliks of Hoshiarpur, which occupy the local Siwalik range beyond the low ground of the Sohan tributary. The "Boundary Fault" can be traced south-eastwards to the hills below Nahan, though often obscured by post-Tertiary deposits. To the northwest the Budsur and Kesori faults die out and the structure becomes less complicated. The Nurpur fault, arising northwest of Jwalamukhi is regarded by Pilgrim as a branch of the Gumber fault and appears to be cut off southwards by a cross fault crossing the Jwalamukhi range.

This Hoshiarpur portion of the Siwalik range is an anticline with low northeasterly dips on the northwest flank; along the southwestern fringe of the range Upper Siwalik beds are described by Lahiri as overthrust on to almost horizontally disposed alluvial strata forming part of what is known as the "Older Gangetic Alluvium", which cannot be much later than late Pleistocene and merges into the Recent alluvium of the Ganges. In the State of Nelagarh, southeast of the Naina Devi ridge and Solasinghi range, along the eastern edge of the Nalagarh *dun*, Dagshai beds appear to have been pushed south-westwards over the alluvial clays and conglomerates of the *dun*.[154]

From the Beas the Nahans can be recognised and traced to the Ravi, and are succeeded by the Middle and Upper Siwaliks. The term Nahan may be retained as a useful designation for the particular type of Lower Siwalik beds found along this sub-Himalayan belt.

The Nahan group.—The Nahan group is composed of alternating beds of sandstone and clay. The sandstone is described by Heron as coarse and micaceous, occurring in thick beds with little stratification and sparse jointing[155]; it is softer and coarser than the Kasauli sandstone, which it resembles in many other ways, and is usually of a lighter grey colour. The superior degree of induration of the Kasauli or Dagshai sandstones compared with that attained by the Nahan sandstones is well seen in places where the two are brought into juxtaposition by faulting; while the latter always weather into slabs with smooth surface and rounded edges, the older sandstones break down into comparatively sharp-edged blocks or fragments resulting from the characteristic system of irregular jointing. Nevertheless the Nahan sandstones are hard enough to be dressed into blocks and used for building purposes and are definitely more

[153] Gen. Rep. Rec. 54, 21-22 (1922).
[154] Gen. Rep. Rec. 69, 73 (1935).
[155] Gen. Rep. Rec. 71, 19 (1936).

indurated than the sand-rock of the Middle Siwalik. The Nahan clays, mostly bright red in colour and almost always of some shade of red or purple, weather in a nodular manner. Generally the clays prevail in the lower part of the group and sandstones in the upper. Concretionary clay conglomerates also form part of the Nahan sequence, as they do so typically in the Lower Siwaliks of other regions including the distant one of Sind. From the Beas the Nahans can be recognised and traced to the Ravi, and are succeeded by Middle and Upper Siwaliks; in a south-eastward direction the Nahans have been identified in the foot-hills of Nepal.

About 500 feet below the top of the Nahan group, *Conohyus chinjiensis* Pilg., a characteristic Chinji species, has been collected south of Haritalyangar.[156] Pilgrim thinks it highly probable that to the Nahan beds are to be attributed some remains of *Progiraffa sivalensis* Lyd. from Rurki, a *Dinotherium* tooth and another tooth doubtfully referred to *Anthracotherium* (*Microbunodon*) *silistrense* (Pentl.).[157] From the base of the Lower Siwaliks, 23 miles north and west of Bilaspur comes the Rodent, *Rhizomys punjabiensis* Colb.[158]

Post-Nahan Siwaliks.—In those sections where the sequence is believed to be complete, the Nahan group is succeeded by an immense thickness of soft sandstones, generally coarser and more micaceous, mostly of a pepper-and-salt grey colour, with some interbedded bands of earthy clay, some of which is tinged with red. The argillaceous beds are, for the most part, confined to the lower part of the succession, the middle being usually composed of some thousands of feet of sandstones without any shale intercalations on the one hand, or any included pebbles on the other. In the upper part of this sequence strings of pebbles occur among the sandstone, and become more numerous till bands of conglomerate begin to take their place and increase in abundance and coarseness. It is possible that the Tatrot stage may be represented in the basal portion of these beds, but by far the bulk of them belong to higher stages of the Upper Siwalik. For the Upper Siwalik of this region ,where it is best developed, Pilgrim allows a total thickness of something like 10,000 feet. The fauna, characterised by *Equus*, *Bos*, *Elephas*, *Camelus* and the giraffoid, *Sivatherium*, is distinct from that of the Middle Siwalik, and there is remarkably little overlapping of species.[159] The Nahan group is responsible for the Jwalamukhi as well as the Solasinghi ridge, and in these sections passes up quite gradually into grey sandstone and red clays of Middle Siwalik age, and the latter into Upper Siwalik sand-rock, conglomerate and boulder beds.[160]

Nurpur Beds.—Throughout Kangra and Bilaspur, and in the hill States there occurs at the summit of the thick mass of Nahan sandstones a constant zone of red, calcareous, nodular clays which

[156] Gen. Rep. Rec. 55, 41 (1923).
[157] Rec. 40, 193 (1910).
[158] Amer. Mus. Novit. No. 633, 1-3 (1933).
[159] Rec. 40, 191-192 (1910).
[160] Gen. Rep. Rec. 68, 66 (1934).

closely resemble the Chinji beds of the Salt Range except for the few occasional pebbles in the beds;[161] some pisolitic pyritous horizons are also found among these beds. The lithological change from typical Nahan sandstones into beds composed chiefly of red clay is sudden and provides an easily mapped boundary. These Nurpur beds, as they have been called, are only 20 feet thick in the western part of Kangra but thicken out to about 1,000 feet in the eastern part of the district, and to more than 2,000 feet at Haritalyangar in the State of Bilaspur. The red Nurpur beds pass up gradually into an immense thickness of pebbly sandstones with interbedded clays, ending ultimately in a boulder conglomerate stage. At Haritalyangar, which is near the Kangra boundary, remains of vertebrates have been found by Pilgrim and Vinayak Rao throughout a vertical succession of some 6,000 feet of strata and afford evidence of a conformable sequence from Nahan beds with the typical Chinji species, *Conohyus chinjiensis* and *Rhizomys punjabiensis* into richly fossiliferous Middle Siwaliks; while the lower portion of the latter contains a fauna which is approximately the equivalent of the Nagri stage of the Potwar, the upper has yielded numerous fossil species which leave no doubt as to its Dhok Pathan age. No Upper Siwalik fossils have been collected from this locality, and it is possible that both the Tatrot and Pinjor stages are missing, since a great thickness of conglomerates, probably assignable to the Boulder Conglomerate stage, overlies the beds with Dhok Pathan fossils. If the correlation is correct, it indicates the existence of a great unconformity between the Boulder Conglomerate stage and the middle Siwalik.[162]

Nagri stage.—The Nagri stage of the Haritalyangar area comprises some 3.500 feet of sediments. Fossils are plentiful in the upper 2,000 feet but less frequent in the 1,500 feet which form the lower portion. The lowest well marked fossil zone occurs at the junction of these two portions, *i.e.*, at a level some 1,500 feet above the top of the Nahans; it is characterised by the frequency of *Hipparion*, and from it the bulk of the following Nagri fossils recorded from this area have been collected.[163]

PRIMATES.

Sivapithecus indicus Pilg.,
Sivapithecus himalayensis Pilg. (referred by Lewis to *S. indicus*),
Sivapithecus orientalis Pilg. (referred by Lewis to *S. indicus*),
Palaeopithecus (?) *sylvaticus* Pilg. (referered by Lewis to *Sivapithecus sivalensis* Lyd.).
Ramapithecus brevirostris Lewis,
Bramapithecus (?) *sivalensis* Lewis,
Sugrivapithecus salmontanus Lewis,
Sugrivapithecus gregoryi Lewis,
Hylopithecus hysudricus Pilg.,
Indraloris lulli Lewis (a lemuroid).[164]

[161] G. E. Pilgrim, Rec. 43, 268 (1913).
[162] Gen. Rep. Rec. 55, 41 (1923).
[163] G. E. Pilgrim, Private Communication.
[164] Amer. Journ. Sci. (5)26, 134 (1934).

RODENTIA.

Rhizomys nagrii Hint.,[165]
Rhizomys pilgrimi Hint.,
Kanisamys sivalensis A. Elmer Wood[166],
Sayimys perplexus A. Elmer Wood[166],
Sivanasua himalayensis Pilg.,
Crocuta gigantea Schlosser, var. *latro* Pilg.,
Megantereon (?) *praecox* Pilg.

PROBOSCIDEA.

Stegolophodon cf. *cautleyi.*

PERISSODACTYLA.

Hipparion theobaldi Lyd.,
Chalicotherium (?) sp.,
A rhinocerotine.

ARTIODACTYLA.

Anthracotherium (*Microbunodon*) *silistrense* Pentl..
Anthracotherium sp. (larger than the preceding and having an entirely different lineage),
Hemimeryx pusillus (Lyd.),
Listriodon pentapotamiae (Lyd.),
Lophochœrus nagrii Pilg.,
Lophochœrus himalayensis Pilg.,
Propotamochœrus salinus Pilg.,
Propotamochœrus uliginosus Pilg.,
Dicorphochœrus robustus Pilg.,
Sus advena Pig. (perhaps from the Dhok Pathan of the succession),
Dorcubune nagrii Pilg.,
Dorcatherium minus Lyd.,
Giraffokeryx punjabiensis Pilg.,
Vishnutherium (?) sp. (similar to a species found at Nagri),
Giraff, small species,
Pachyportax cf. *nagrii* Pilg.

Dhok Pathan stage.—Above this fossiliferous Nagri zone of Haritalyangar fossils are plentiful through a thickness of some 2,000 feet and include some typical Dhok Pathan species which are given below ; between the Nagri beds and those of Dhok Pathan age which succeed them it is impossible to draw an exact line of demarcation either lithologically or faunistically.

CARNIVORA.

Lutrine gen. indet. *hasnoti* Pilg.,
Sivaonyx bathygnathus (Lyd.),
Ictitherium sivalense Lyd.

PROBOSCIDEA.

Stegolophodon cf. *latidens.*

PERISSODACTYLA.

Rhinocerotine.
Hipparion theobaldi Lyd.,
Hipparion punjabiense Lyd.

[165] Ann. Mag. Nat. Hist. (10), 12, 62 (1933)
[166] Amer. Journ. Sci. (5), 24, 70 (1937).

ARTIODACTYLA.

Anthracotherium (Microbunodon) silistrense Pentl.,
Dorcatherium majus Lyd.,
Tetraconodon mirabilis Pilg.,
Hydaspitherium megacephalum Lyd.,
Selenoportax lydekkeri Pilg.,
Tragoportax cf. *islami* Pilg.,
Tragocerus cf. *panjabicus* Pilg.

From an horizon midway between the above Nagri and Dhok Pathan faunal zones of Haritalyangar comes *Tetraconodon mirabilis* Pilg. Following the Dhok Pathan fossil beds of this locality and separated therefrom by a suspected unconformity is a great thickness of unfossiliferous conglomerates which probably belong to the Upper Siwalik;[167] if this be correct the Pinjor stage would appear to be missing here.

Pinjor stage.—The town of Pinjor, which is situated to the south of Kalka near the eastern edge of the so-called Pinjor Dun between the rivers Sutlej and Ghaggar, has given its name to the sand-rock stage of the Upper Siwaliks. The outer range of hills, adjoining the Pinjor Dun, consists mainly of a soft, massive, greyish white sand-rock, interbedded with subordinate orange and pinkish clays.[168] They are disposed in an anticlinal flexure, the axis of which is situated at distances varying from nothing up to a mile from the edge of the Dun. These beds, the oldest of the succession, have yielded several fossils. The remainder of the section, which is from 5 to 7 miles in length, embraces the southwestern limb of the anticline, in which higher and higher beds of the Pinjor stage are exposed, until near the edge of the plains they pass up into the Boulder Conglomerate, which is thickest near Rupar. The total thickness of the Pinjor stage here is about 5,000 feet.

A cross fault separates the Pinjor range from the hills across the Ghaggar river. In these hills the beds dip regularly to the northeast. The oldest beds of the Pinjor stage are here adjacent to the plains; with a constant dip of about 25° and attaining even a greater thickness than in the Pinjor range, they eventually pass up into the Boulder Conglomerate which is in this section about 3,000 feet thick. About 1,000 feet above the basal beds of this section, near the village of Moginand and not far from the Ghaggar river is the famous fossil locality from which Baker and Durand in 1836 excavated large numbers of the specimens which were subsequently described and figured by themselves, Falconer or others.[169] Lithologically the beds between the Ghaggar and the Jumna are of precisely the same type as those of the Sand-rock stage of Garhwal and Kumaon described by Middlemiss.

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[167] Gen. Rep. Rec. 55, 41 (1923).

[168] Gen. Rep. Rec. 69, 72 (1935).

[169] W. E. Baker and H. M. Durand J. A. S. B., 5, 488 (1836); H. Falconer, Pal. Mem., 1, 244 (1868).

From the Pinjor range and from the hills which continue it to the southeast the first Siwalik fossils were collected more than a hundred years ago by Falconer, Cautley and their co-workers, and it is from this area that most of the Siwalik hill specimens have been collected in recent years. Many additional specimens were obtained by Theobald about the year 1875 in the Siwalik ranges to the northwest of the Sutlej, in the Hoshiarpur district adjacent to the so-called Una Dun. Practically all the Upper Siwalik species were founded on the original material, of which unfortunately the stratigraphical position and, except in a few instances, the locality, were not recorded. Out of a total of 85 species only 22 have been rediscovered, so that we are left with very inadequate knowledge of the exact position which 75 per cent. of them occupy. At first it was thought that a large proportion came from the Boulder Conglomerate stage, but later examination has shown that very few are likely to have belonged thereto, and that scarcely more than half-a-dozen species can be said with certainty to occur in it. It is still open to suspicion that some of the specimens come from the Tatrot stage, especially those which are plentiful in the Salt Range beds of that stage, but the bulk of the fauna collected from the Siwalik hills belongs to the Pinjor stage.

Before detailing the fauna of the Pinjor stage, mention must be made of certain highly lignitiferous marls which occur on the plains side of the hills between the Jumna and the Ghaggar ; Falconer has referred to these beds and in particular to a deposit in the Kalawala pass (Kalawala Rao) which is said to have yielded a large collection of fossils, most of them strongly pyritised. A provisional list is given, but, with the exception of a milk tooth doubtfully referred to *Anthracotherium* (*Microbunodon*) *silistrense,* the specimens are either lost or have been mixed with other Siwalik hill specimens now preserved in the museums of London or Calcutta. The deposit in the Kalawala Pass was found by Pilgrim as described by Falconer, but the only specimen recovered therefrom was one of *Hipparion,* and it seems likely that the bed was but a pocket. At first it was thought that the deposit might represent the Nurpur zone of Kangra and occupy a position in the Middle Siwalik ;[170] later this view has been discarded in favour of a possible Tatrot age.[171] *Anthracotherium silistrense* is a species of wide range and a specimen of it has been found so near to Tatrot as to make it possible that it should have been derived from the Tatrot stage. *Presbytis palaeindicus* (Lyd.) has been found in the Siwalik Hills and may indicate the presence of a Tatrot horizon.[172] On the other hand, *Hipparion* is so frequent among the fossils collected by Falconer and Cautley, and the preservation of the specimens so exactly like that of the other Siwalik hills fossils, that one is practically forced to accept the inclusion of

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[170] Rec. 40, 193 (1910).

[171] G. E. Pilgrim, Pal. Ind., New Ser. Vol. 18, 3 (1932).

[172] Rec. 72, 472 (1937).

Hipparion in the Pinjor fauna.[173] It must for the present, however, remain an open question whether any part of the Tatrot stage is represented in the Siwalik hills or whether the whole fauna throughout the 5,000 feet of strata is of approximately the same age. We might well expect to find sections where the Tatrot fauna shades imperceptibly up into that of the Pinjor, especially in deposits such as these which are on the whole conformable throughout and seldom altogether devoid of fossils.

The following is a list of forms from the Pínjor stage of the Siwalik hills:

MOLLUSCA.

Lamellidens lewisi Vokes.

PRIMATES.

Papio falconeri Lyd.,
Papio subhimalayanus H. V. Meyer.
Presbytis (Semnopithecus) palaeindicus Lyd.,[174]
Simia cf. *satyrus* Linn.

RODENTIA.

Rhizomys pinjoricus Hint.,[175]
Nesokia cf. *hardwicki* Gray,
Hystrix cf. *leucurus* Sykes.

LEPORIDAE.

Caprolagus sivalensis Major.

CARNIVORA.

Canis cautleyi Bose, (related to the Indian wolf),
Sivacyon curvipalatus (Bose) (related to *Vulpes bengalensis*),
Agriotherium sivalense (Falc. & Cautl.),
Melursus (?) *theobaldi* Lyd. (the earliest true bear in India; *M. Labiatus* or *ursinus* is the modern sloth-bear, so much in favour among Indian jugglers),
Sinictis (?) *lydekkeri* Pilg.,
Mellivora sivalensis (Falc. & Cautl.),
Lutra palaeindica (Falc. & Cautl).,
Enhydriodon sivalensis Falc.,
Viverra bakeri Bose (related to *V. civetta* and *V. genetta*),
Vishnuictis durandi (Lyd.),
Hyaenictis bosei Matth.,
Crocuta sivalensis (Falc. & Cautl.) (closely allied to the Villafranchian, *C. brevirostis*),
Crocuta felina (Bose),
Crocuta colvini (Lyd.),
Megantereon (?) *palaeindicus* (Bose),
Megantereon (?) *falconeri* Pomel, (somewhat more progressive than the widespread *M. megantereon* of the European Villafranchian),
Felis subhimalayana Bronn.,
Panthera cristata (Falc. & Cautl.), (cf. the Pliestocene and Recent, *Felis tigris*),

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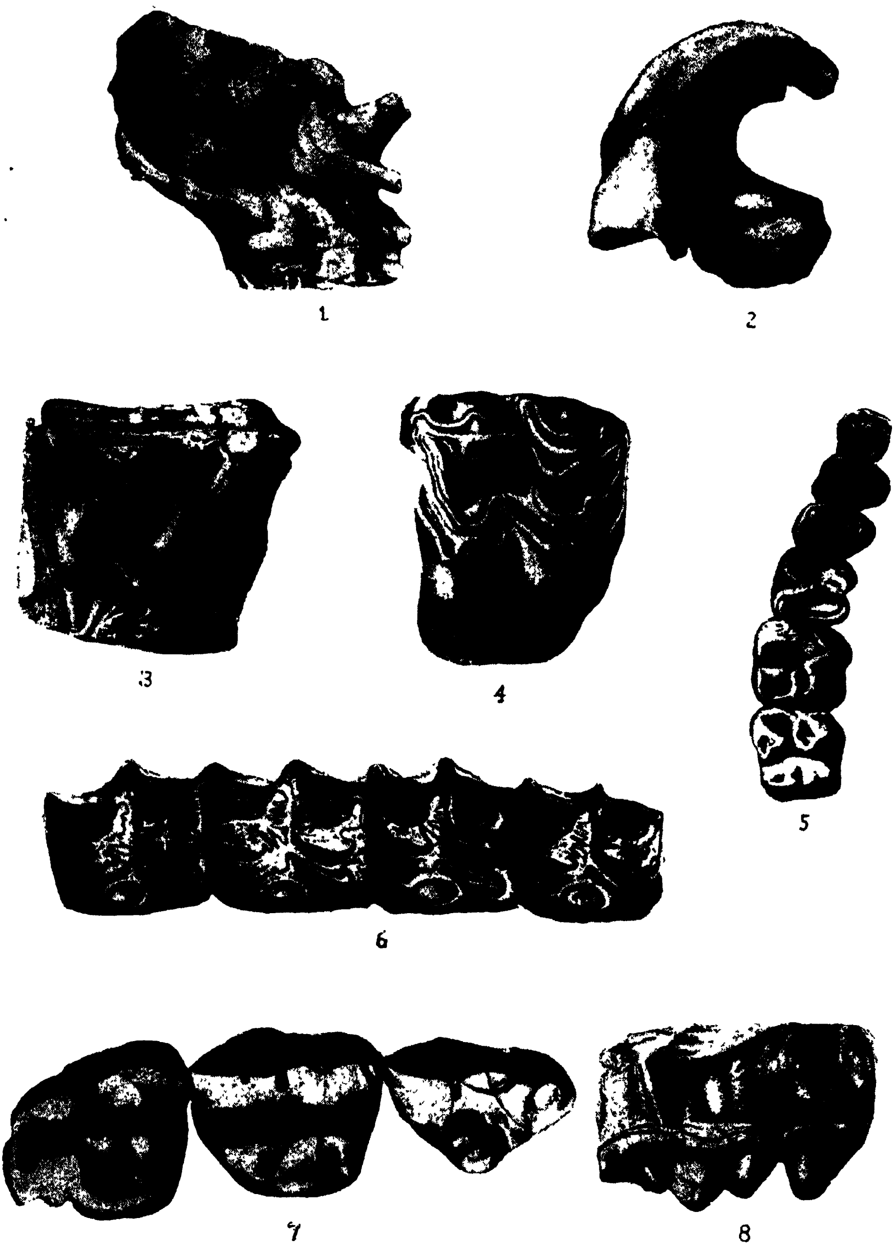
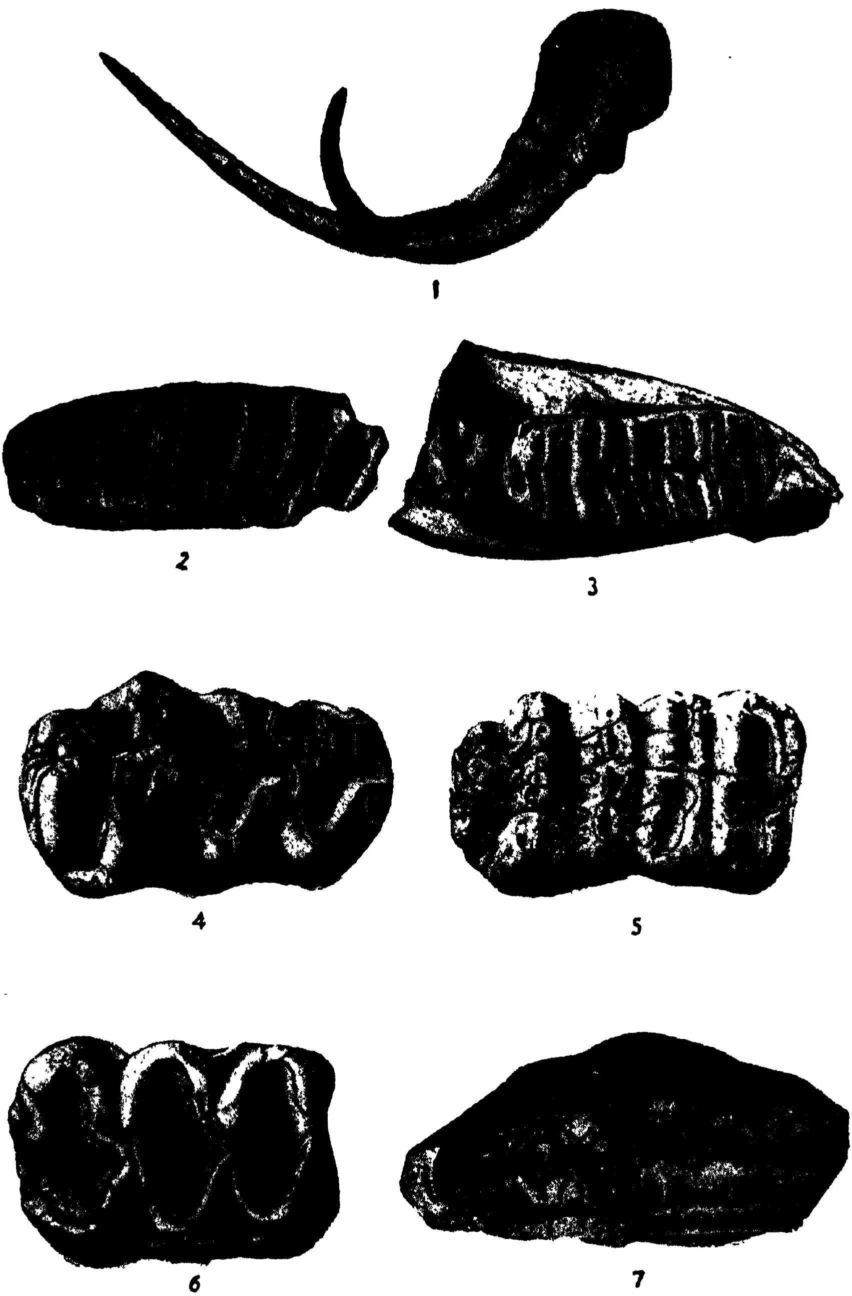
[173] G. E. Pilgrim, Private Communication.
[174] Gen. Rep. Rec. 45, 106 (1915).
[175] Ann. Mag. Nat. Hist., Ser. 10, 12, 621 (1933).



SIWALIK FOSSILS (A)

1. *Sivatherium giganteum* Falc. & Cautl. (×1/13). 2. *Sivacapra sivalensis* (Lyd.) (×1/4) 3. *Rhinoceros sivalensis* (Falc. & Cautl.), Right upper molar (×2/3). 4. *Giraffa sivalensis* (Falc. & Cautl.), Left upper molar (×1). 5. *Papio subhimalayanus* (H. v. Meyer), Right upper molar (×1). 6 *Hipparion antelopinum* (Falc. & Cautl.), Left lower molars and premolars (×1) 7. *Agriotherium palaeindicum* (Lyd.), Right upper molars and premolars (×1). 8. *Crocuta colvini* (Lyd.), Right upper premolar (×1)

G. S. I., Calcutta.



SIWALIK FOSSILS (B)

1. *Stegodon ganesa* (Falc. & Cautl.), Cranium (X1/50) 2. *Stegodon ganesa* (Falc. & Cautl.) (X1/4). 3. *Elephas hysudricus* (Falc. & Cautl) Left lower molar (X1/3). 4. *Mastodon (Trilophodon) falconeri* (Lyd.), 2nd right lower molar (X1/3). 5. *Mastodon latidens* Clift 2nd right upper molar (X1/3). 6 *Dinotherium giganteum (indicum)* (Falc. & Cautl.), Left lower molar (X1/2). 7. *Sus hysudricus* Falc. & Cautl., Right upper molar (X1).

G. S I., Calcutta.

Sivafelis potens Pilg.,
Sivafelis brachygnathus (Lyd.) (closely allied to *Felis arvernensis* of Europe and *Cynaelurus pleistocaenicus* of the Chinese Nihowan).

PROBOSCIDAE.

Mastodon (Pentalophodon) sivalensis (Cautl.),
Stegolophodon stegodontoides (?) Pilg.,
Stegodon ganesa (Falc. & Cautl.),
Stegodon bombifrons (Falc. & Cautl.),
Stegodon pinjorensis Osb.,
Hypselephas hysudricus (Falc. & Cautl.), (regarded by Pohlig as a variety of the Upper Pilocene elephant of Europe, *E. meridionalist*),[176]
Platelephas platycebhalus (Osb.).
Elephas (Archidiscodon) planifrons (Falc. & Cautl.) (Abundant, a well known European form).

PERISSODACTYLA.

Equus sivalensis Falc. & Cautl. (has the short muzzle and deep jaw characteristic of early Pleistocene species, both in America and the Old World, as compared with Equus caballus *E. sivalensis* and *E. namadicus* are caballine forms of the horse),
Equus namadicus Falc. & Cautl.,
Equus cautleyi (a zebrine form),
Nestoritherium sivalense Falc. & Cautl., (*Nestoritherium* is probably a descendant of *Chalicotherium*),
Coelodonta (Dicerarhinus) platyrhinus (Falc. & Cautl.) (related to the Upper Pliocene, *D. etruscus* of Europe)
Rhinoceros sivalensis Falc. & Cautl.,
Rhinoceros palaeindicus Falc. & Cautl., (regarded by Matthew as synonymous with *Rh. sivalensis*).

ARTIODACTYLA.

Sivachoerus giganteus (Falc. & Cautl.), (near the base of the stage ; according to Pilgrim *Sivachoerus* and *Tetracondon* are derived from *Conohyus*).
Tetraconodon magnus Falc.,
Potamochoerus theobaldi Pilg. (upper part of stage ; genus of the African river hog),
Potamochoerus hysudricus,
Dicoryphochoerus durandi Pilg.,
Hippohyus sivalensis Falc. & Cautl.,
Sus hysudricus Falc. & Cautl.,
Sus bakeri Pilg.,
Sus falconeri Lyd.,
Sus cautleyi Pilg.,
Merycopotamus dissimilis Falc. & Cautl.,
Hippopotamus (Hexaprotodon) sivalensis Falc. & Cautl.,
Camelus sivalensis Falc. & Cautl., (not very different from the modern *C. bactrianus*),
Camelus antiquus Lyd. (Matthew doubts its distinction from either *C. sivalensis* or *C. bactrianus*),
Cervus sivalensis Lyd.,
Cervus punjabiensis Brown,
Cervus simplicidens Lyd.,
Sivatherium giganteum Falc. & Cautl.,
Indratherium majori Pilg., (considered by Mathew to be synonymous with *Sivatherium giganteum*),
Giraffa sivalensis Falc. & Cautl.,
Vishnumeryx daviesi (Lyd.),

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[176] Rec. 43, 325 (1913).

Antilope subtorta Pilg.,
Sivacapra sivalensis (Lyd.), (the earliest known undoubted goat in India),
Sivacapra (?) *crassicornis* Pilg.,
Sivoryx cautleyi Pilg.,
Sivoryx sivalensis (Lyd.),
Sivatragus bohlini Pilg.,
Vishnucobus patulicornis (Lyd.),
Indoredunca sterilis Pilg.,
Gangicobus asinalis Pilg.,
Sivadenota biforis Pilg.,
Sivacobus palaeindicus (Lyd.),
Damalops palaeindicus (Falc.),
Hemibos triquetricornis Rut.,
Hemibos acuticornis (Falc. & Cautl.),
Hemibos antilopinus Rut.,
Bubalus platyceros Lyd.,
Leptobos falconeri Rut.,
Bucapra daviesi Rut.,
Platybos aceros (Rut.),
Gen. indet. (cf. *Platybos*) *platyrhinus* (Lyd.),
Bos acutifrons Lyd.,
Bison sivalensis Lyd.

While the type locality of the Tatrot stage is the Tatrot plateau of the Salt Range, that of the Pinjor is the Pinjor range of the Simla foothills, and the two stages are not found together in any appreciably fossiliferous and readily recognisable form. Their individuality has been questioned, but there are several members of the meagre Tatrot fauna which are not found in the rich Pinjor assemblage, and the former is regarded by Pilgrim as definitely more primitive as regards the Bovidae, antelopes and some of the pigs, and equivalent to the Astian of Montpellier in Europe. Hopwood, from a study of the Proboscidea, finds that the Pinjor with its abundance of *Elephas planifrons* resembles much more closely the Villafranchian than it does the Sicilian or Cromerian with *Elephas antiquus*; this authority suggests that *Mastodon sivalensis* of the Pinjor and *M. arvernensis* Cr. & J. of the Villafranchian might even be geographical races of one species. In the Tatrot, *Stegodon* predominates over *Mastodon*, *Elephas* and *Equus* have only just made their appearance, *Hipparion* has survived, and *Hippopotamus* is abundant. In the Pinjor, *Stegodon* and *Hipparion* are still in existence, while *Elephas*, especially in the form of *E. planifrons*, has become abundant. The genus *Elephas* is thought by Pilgrim to have originated in India and to have migrated thence into Europe.[177]

Boulder Conglomerate stage.—The uppermost stage, the Boulder Conglomerate, is remeniscent of, but less cemented and coarser than, the Molasse Nagelfluh of the Swiss Alps. It is found in thick beds at various places along the inner boundary of the Tertiary belt, faulted against old metamorphic beds. It is seen in the hills below Dalhousie and continues almost as far as Dharmsala, and is again seen between Baijnath and Mandi and also in Bilaspur.[178] It varies

[177] G. E. Pilgrim, Rec. 43, 295 (1913).
[178] Gen. Rep. Rec. 41, 84 (1911).

much in character. Near the large rivers draining the central Himalaya, it consists principally of coarse conglomerate, composed of rounded boulders of the harder rocks of the Himalayan chain ; among them are pebbles of Nahan sandstone. In the intermediate stretches of ground, it is composed largely of soft earthy beds precisely similar to those of the modern alluvium of the plains. Below Simla the pebbles of the conglomerates consist mostly of Dagshai and Kasauli sandstone ; further north they are mainly of quartzite and other metamorphic rocks.[179]

In the country traversed by the Sutlej there is a gradual passage from the Pinjor beds upwards into the Boulder Conglomerate stage. The conglomerates of the latter are here associated with white or brownish sand-rock and pink and brownish clays, which are particularly abundant towards the top of the stage and often indistinguishable from recent alluvial deposits. A fossiliferous horizon above the Pinjor sand-rock near Bhaddi has yielded teeth of *Equus, Elephas* and bovine animals, as well as some fresh-water unionids.

Contrary to former opinion, vetebrate remains are rarely found in the Boulder Conglomerate, and only some four species, *Bubalus palaeindicus* Falc., *B. platyceros* Lyd., *Stegodon ganesa* Falc. & Cautl., *Stegodon insignis* Falc. & Cautl., *Elephas hysudricus* Falc. & Cautl., *Platelephas platycephalus* Obs., and *Equus namadicus* Falc. & Cautl. are known with certainty to have been obtained therefrom. It should be remembered that *Elephas planifrons, Equus* and *Camelus* are all found as much as 5,000 feet below the base of the Boulder Conglomerate.

Throughout the greater part of the Himalayan foothills, the Siwalik Boulder Conglomerate is sharply marked off from the extensive Recent gravels and boulder deposits which are still accumulating ; here and there, however, where the Upper Siwaliks have suffered the minimum disturbance, no definite line of division can be drawn between them, and it is obvious, both from this and the mutual similarity of composition, that the Recent material is but the immediate successor of the Siwalik and derived from the same source. The concentration of the coarser Upper Siwalik deposits as well as of the Recent gravels and boulder beds around and debouchures of the large rivers, moreover, shows that both the older and younger material has been transported along these same channels.

Garhwal and Kumaon.—In Garhwal and Kumaon the Siwaliks form the same great conformable and connected sequence, the oldest being much more consolidated than the youngest. The average total thickness, according to Middlemiss, is at least 16,500 feet, so that the succession is in all probability a full one, although the various stages of the Punjab have not yet been established therein. In this region especially, progressive disturbance has produced the condition of marked unconformability between the uppermost and lowermost beds with continuous conformability, generally speaking, between consecu-

[179] Gen. Rep. Rec. 69, 73 (1935).

tive stages. The rocks are folded into anticlines and synclines, the folding becoming tighter inwards towards the centre of the range. The beds are displaced by two or three large strike faults and end along their inward side at the so-called "Great Boundary Fault" over which the older Himalayan rocks have been thrust S.S.W. 'wards. Between the Jumna and Ganges, the Siwalik range is occupied by an anticline whose axis is slightly oblique to the general direction of the range;[180] to the northeast a syncline forms the Dehra Dun valley and is succeeded further in the same direction by an overturned anticline truncated on the northeast side by the "Main Boundary Fault" which is here the Krol thrust. For nearly 40 miles, in the Patli and Kotah Dun areas, the Upper Conglomeratic subdivision lies with a very pronounced unconformity on the Nahans. Three subdivisions have been recognised, which it will be safest to name as follows:

(c) Siwalik Conglomerate.

(b) Sand-rock group.

(a) Nahan sandstone.

The base of the Nahan Sandstone, which presumably coincides with the Nahan stage of the Simla Hills, is nowhere seen, but there is a visible thickness of 6,270 feet in the Kotri river and just under 5,000 feet in the Pelani stream.[181] The prevailing tints of the sandstone are brown or greenish-brown; sometimes the rock is of a bluish grey colour. It is very micaceous, occasionally felspathic, and never so purely siliceous as the sand-rock of the following group, containing an appreciable amount of earthy and secondary ferruginous material. Unlike the sand-rock the Nahan sandstone of this area is traversed by numerous joints which split the rock into blocks and slabs and is more marked in the lowermost horizons. Interbedded with the sandstone, especially in lower horizons, are finely laminated, purple, dark reddish brown and greenish shales. Conglomerates similar to the clay conglomerates of the sand-rock above are sometimes seen but are generally more compact and more firmly aggregated. In the upper horizons there are some concretionary layers of the same nature as, but less distinct than, those in the group above. In some of the lower purple shales there are ferruginous bands which in one case swell out into considerable beds of brown hematite and were at one time smelted for iron.

The Sand-rock group, into which the Nahans merge conformably, is less indurated and lighter in colour. Wherever it crops out, the country is in a state of rapid disintegration. The thickness of this group is great and appears sometimes to vary inversely as the thickness of the Siwalik Conglomerate. Along the Ramganga, from the Nahan boundary up to the Siwalik Conglomerate, 7,260 feet are estimated, while in the Kotri river the thickness of the corresponding band is 8,910 feet.

[180] J. B. Auden, Rec. 71, 415 (1936).

[181] Mem. 24, 87 (1890).

The basis of the prevalent bed is a micaceous, slightly ferruginous, sometimes felspathic, but comparatively pure sand. Pale ochre colours prevail, but these are commonly associated with pale blue grey, chocolate and pale purplish tints in a banded coloration ; sometimes to a pepper-and-salt colour. The texture is sugary and the rock unjointed and without divisional planes generally. A characteristic feature of the sand-rock is the presence of numerous nodular layers of the nature of concretions, sometimes massed into a thin tabular layer and varying in thickness from a few inches up to two feet. These layers, with their wavy and mammillated surfaces, become hard enough to ring unmistakably under the hammer and to stand out in relief in exposed sections. Sometimes they are replaced by disjointed masses, some of them remarkably spherical in shape, others having the grotesque form so often assumed by flints, and others again so like flattened pebbles that, were it not for the coincidence of their bedding with that of the matrix, they might be taken for transported clastic material.

True pebble beds occur, but the pebbles are always insignificant in size and of a different composition from those in the Conglomerate group higher up. About ¼ inch across and consisting of white quartz, they lie in thin strings, and are sometimes accompanied by thin layers of ferruginous concretions which give a dark brown appearance to the rock. Another kind of conglomerate is made up of rolled clay balls, either scattered sparsely through a sandy matrix, or crowded together. The clay pebbles, of a brownish ochre, are soft enough to be scratched by the fingernail, and are sometimes accompanied by a few pebbles of brown sandstone.

Reddish brown clays are freely interstratified with the sandstones, and grey clays and loams are very prevalent in the uppermost horizons of the group ; when nodular in character they resemble the clay conglomerates. Nests and strings of lignite and coaly material are very common ; in most cases they are very small, but occasionally a somewhat larger tree-trunk has been fossilised.[182]

Generally speaking, the upper portion of the Sand-rock group is largely composed of the sandy and loamy beds, the concretionary layers come in lower down, and lower still the fine quartzose conglomerates and the clay conglomerates. The concretionary layers and the conglomerates continue down to the base of the group and even pass into the Nahan stage below.

The thickness of the Siwalik Conglomerate is very variable and, as it does in other regions, increases in proximity to a large river Across the ridge south of the Patli Dun, a calculation gives a thickness of 2,970 feet. This group passes down in to the Sand-rock group, with rapid but gradual interbedding. It is composed of generally well rounded and very seldom somewhat angular material of much the same character as that which is now accumulating in

[182] Mem. 24, 24-26 (1890).

the stream beds. Lying in a matrix of buff or dark yellow, earthy sand, the pebbles are of large size and are composed chiefly of the older Himalayan rocks; the following is a list of rock-types of which the pebbles are composed:

Older Himalayan rocks.	Purple white or grey quartzite	—most common.
	Purple and grey slate.	—common.
	Purple and greenish, gritty quartzites.	— ,,
	Fine conglomerate.	— ,,
	Vein quartz.	— ,,
	Lydian stone.	—rare.
	Decomposed greenstone.	— ,,
	Well preserved trap.	—common locally
	,, ,, granite.	— ,, ,,
Older Tertiary.	Soft, brown or pepper-and-salt sandstone (Nahan).	—common locally.
	Greenish grey shales.	—rather common.
	Ochreous and dark brown shales.	— ,, ,,

In places the conglomerate is composed almost entirely of large blocks of Nahan sandstone. Many clay and loamy bands, of brown and yellow colours are interstratified with the ordinary conglomerate; they increase in quantity low down in the formation, and are studded here and there with pebbles. Current-bedding is very common, and the rock is hardened in places by a deposit of carbonate of lime between the pebbles. Very little horizontal variation in the material forming the conglomerate pebbles has been noted. The presence in eastern Kumaon of well preserved granite and trap pebbles in large numbers is clearly due, as Middlemiss remarks, to the outcrops of the parent rocks immediately north of the sub-Himalayan zone. A very constant character of the conglomerate is the alternation of coarse and fine bands, and the interbedding of sandy, loamy and clay beds. As a whole, the Siwalik Conglomerate group may be said to be more ferruginous and to be composed of coarser material in its upper part than at lower horizons; in the latter the partings of sandy clay become more frequent, and the material of the conglomerate finer on an average, though beds of different-sized pebbles alternate as they do higher up.

In the majority of cases the Siwalik Conglomerate is here sharply marked off from Recent deposits by a distinct unconformity. Wherever it is comparatively undisturbed and flattens out into a gentle anticline or syncline, however, as in the Patli Dun and the eastern end of the Kotah Dun, the division between Siwalik and Recent deposits was found by Middlemiss to be made impossible on petrological grounds, especially where Recent gravels had been cemented and hardened by the deposition of carbonate of lime.

Nepal.—Of the foot-hills of western Nepal there is scarcely any geological information. The Dundwa or Dun range is said to consist of Siwalik rocks. East of the Gandak the Sumesar (Sumeswar) range is made up of the same beds; beyond this and to the southwest of Kathmandu a belt of Siwalik rocks has been mapped by Medlicott and recently again by Auden, lying between the alluvium of the plains and the great thrust-plane which has brought the ancient Daling

series, or in places Gondwana beds, over the Tertiaries. This belt, with a width of from 12 to 13 miles, extends eastwards across the Bagmati, past Udaipur, to within a few miles of the Kosi (Sapt Kosi) river, where it becomes concealed beneath the alluvium. Below Kathmandu the Churia Ghati range is, in size, structure and appearance, a *facsimile* of the Siwalik hills further northwest;[183] inside it is an excellent example of a *dun* around Sanotar.

Coming from the hills towards the plains the sequence, with an almost invariable N.N.E.'ly. dip, is:

Nahan or Lower Siwalik,

- - - - - - - Thrust,

Upper Siwalik,

Middle Siwalik,

a thrust separating the Nahans from the underlying Upper Siwaliks.

The Nahans, well exposed on the Udaipur Garhi ridge, are of the usual type, except that they include thin inconstant beds of impure limestone similar to those found to the south of Darjeeling further east.[184] Near Dhukwabas the Siwaliks in places form great cliffs, and consist mostly of sand-rock full of felspar and mica and evidently a denudation product of an adjacent granite or gneiss; their precise age has yet to be determined but they may possibly belong to the Pinjor stage. North of Muksar the Siwaliks probably belong to a lower horizon; here the beds of sandstone are thinner and seldom more than 50 feet thick; calcareous concretions occur and a few thin lenticles of coal.

The Upper Siwaliks are magnificiently exposed at Churia Ghati and on the pass over the Mahamanda Danda. Carved into turreted hills of the same type as those in the Dehra Dun range, the Upper Siwaliks consist chiefly of the usual conglomerates. The commonest pebbles consist of a pale schistose quartzite; among other pre-Tertiary rocks represented in the pebbles, Auden records purple and white quartzite, dark phyllite, arkose, purple and dark pebbly quartzite, as well as silty brown sandstone probably of Nahan age, and tourmaline aplite of unknown age. The older Tertiaries appear to be absent in this region.

Darjeeling.—A little further to the east, the Siwaliks reappear north of Siliguri and have been traced as a belt, irregularly interrupted by forethrust older rocks from the Mechi river across the Tista to the Jaldhaka stream which forms the boundary between the Darjeeling district and Bhutan. Above the Tertiaries throughout most of this section is a thin band of Damuda sediments separating them from the Daling rocks. In the western part of the area the Damuda band dies out and the Siwaliks are in direct contact with the Dalings; in the eastern part the Damuda band is accompanied by an equally thin band of Buxar rocks. There can be little doubt that these

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[183] H. B. Medlicott, Rec. 8, 94 (1875).
[184] J. B. Auden, Rec. 69, 137-138 (1935).

older rocks have thrust over the Tertiaries along the equivalent of the "Main Boundary Fault". One section shows a total thickness of over 11,000 feet of Siwalik beds, with a comparatively steady N.N.W..'-ly dip averaging 35° ; this, however, is probably an anticlinally folded succession and not a continuous sequence.[185]

The Siwaliks of this area are made up mainly of soft massive sandstone and what Mallet describes as "clunchy beds", by which are probably meant lumpy, somewhat indurated clays. The most prominent variety of sandstone is a rather soft, highly felspathic and slightly micaceous medium-grained rock of a pepper-and-salt colour (white with black specks). Other sandstones are of a light buff colour and vary in texture from a rather coarse to rather fine-grained, sometimes passing into fine earthy beds. Near the base of the formation the sandstones contain stray pebbles, well rounded, mostly of white quartz but sometimes of gneiss and schist; higher up these pebbles increase in number and, towards the top, layers and bands of conglomeratic sandstone are frequent. The pebbles are seldom more than 3 inches across and never approach in size to boulders. The sandstones are usually thick, often very massively bedded, and frequently characterised by current-bedding. Some of them contain rounded, concretionary masses of clunch which have the appearance of rolled pieces of foreign rock. The clunchy beds vary in colour from grey to greenish grey, are often micaceous and generally somewhat calcareous; usually the calcareous matter is equally diffused through the rock, but sometimes it is segregated into nodules like potatoes. In a few instances there are layers of impure light grey limestone intimately associated with the clunchy beds. The latter in places become bedded and pass into slightly calcareous grey shale. Some of the dark grey varieties of shale are not unlike unaltered Damuda shales. While the clunchy beds and shale are most abundant in the lower part of the succession, the upper part is characterised by great thicknesses of massive sandstone unmixed with other rock.[186]

Fossil plant stems or trunks, generally more or less flattened by pressure, are frequent in the sandstone, some of them a foot or so in diameter and 10 or 15 feet long. In most of them, according to Mallet, the original woody part is replaced by carbonaceous sandstone, while the bark is represented by brittle jetty lignite, breaking with a conchoidal fracture. In some, however, carbonaceous sandstone and lignite are interbanded throughout the entire thickness of the stem in very irregular layers parallel to the structure of the wood; occasionally the stem consists entirely of lignite and is then generally squeezed quite flat. Besides such recognisable stems and trunks, small irregular masses and strings of lignite are often met with in the sandstone. A few beds of soft, flaky coal, resembling that of the Damudas, have been noted, one of them a lenticular mass swelling to a thickness of 6 feet but extending only for a few yeards laterally. A ferruginous band, varying from a strongly ferruginous clay to an

[185] Denkschr. d. Schweiz. Naturg. Gesells. Bd. 73, Abh. 1, 6 (1939).
[186] F. R. Mallet, Mem. 11, 45-46 (1875).

impure brown hematite, occurs towards the base of the group and appears to correspond to the better known ores in the same stratigraphical position below Naini Tal; Mallet suggests that this ferruginous horizon may be continuous through Nepal.

West Bhutan.—East of the Jaldhaka there is an unusually long gap in the Siwalik outcrop, stretching past the Chamurchi Stockade for some 40 miles and occupied by enormous deposits of Recent boulders. This disappearance of the Siwalik fringe to the hills is, in some parts of the gap, due no doubt to concealment beneath newer sediments and debris; for the most part, however, it is attributable to excessive overthrusting southwards of older rocks. Nine miles west of Buxa, however, the Siwaliks again appear and have been traced as far as the Sankosh river. The sequence comprises a basal 200-300 feet of soft, dark red, slightly micaceous, earthy sandstones and sandy clays mottled red and light green; these beds pass up into the ordinary soft massive standstones, and the succession ends in conglomerate beds which are more largely developed here than in Darjeeling and contain pebbles thrice as thick.[187]

East Bhutan.—From the Sankosh eastwards to a point 19 or 20 miles beyond the Manas, the Siwalik belt has not been surveyed. In the far eastern part of Bhutan, around the debouchement of each river is the usual collection of unstratified drift with numerous pebbles and boulders, overlying blue Siwalik clays and regarded by Pilgrim as of Recent age. Some 10,000 feet of the Tertiaries are exposed dipping with great regularity at 50° or 60° in a northwest direction, along a belt some 5 miles in width.

The outermost beds, all of them strongly jointed, consist of blue clays and some very fine-grained, grey, argillaceus sandstones with occasional intercalations of indurated clay. Further in towards the hills the sandstones become coarser and of the micaceous pepper-and-salt type. Further into the hills come pebbly sandstones which at first contain only a few small pebbles; by the increase in numbers and size of the latter the beds gradually become regular conglomerates with pebbles usually as large as a big orange, some of them equal in size to a man's head.[188] The pebbles are almost invariably of quartzite, never of gneiss; amongst them are fragments of carbonaceous shale. In several places there are nests and stringers of lignite, sometimes with woody structure. Many of the sandstones are highly ferruginous.

Aka hills.—In the country of the Akas, east of Bhutan, there is exposed a considerable thickness of Siwalik beds. In the Bhareli (Bhoroli) section north of Tezpur, the first hills are occupied by unstratified Pleistocene drift, following which is the exposure of Siwalik beds, having an unexpected strike of N.W.-S.E. and a dip to

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[187] F. R. Mallet, Mem. 11, 49-50 (1875).

[188] Guy E. Pilgrim, Rec 34. 23 (1906).

the northeast of 55° and upwards. Cropping out in a belt seven or eight miles across, they consist of light grey sandstones with beds of shale which are sometimes carbonaceous, much crushed and locally contorted; some of the sandstones are micaceous and fissile, and a brown ferruginous variety forms one of the ridges. No lignite has been noticed *in situ* but a fossil tree trunk is recorded, one foot across, coated with a one-inch layer of lignite.[189]

Dafla Hills.—In the Dafla hills the Siwalik rocks occupy a marginal range of thick-bedded fine sandstones with strings of pebbles here and there but no conglomerate; the most conspicuous beds are pepper-and-salt sandstones, and lignite is common.[190] This fringing range of sandstones is separated from the main mountain mass by a broad valley or *dun* drained by the Pomah and terraced in places by bouldery alluvium. Beyond the *dun* come ferruginous sandstones and thick conglomerates with fossil wood, overthrust by the Damuda rocks.

Miri Hills.—In the neighbourhood of the Subansiri gorge Siwalik sandstones and conglomerates in considerable thickness rise abruptly from the plain to heights of 2,000-3,000 feet, showing sheer cliffs of 600-700 feet. The outermost beds are pebbly conglomerates, 10-30 feet thick and dipping at 60° to 70° in a northwest direction; the well rounded pebbles, ranging up to 4 inches in diameter, are composed of rocks identical with those which form the modern stream detritus. Further into the hills the beds suddenly become vertical and the conglomerates disappear along a large fault. On the farther side of the latter the sandstones strike N.W.-S.E. and maintain this direction as far as Gayamukh, some miles up the gorge, where they revert to the original N.E.-S.W. strike. At this point thin intercalations of bluish-grey shale appear with abundant but indistinct vegetable remains. The sandstones as a whole are characterised by the abundance of fragments of semi-carbonised, semi-silicified wood. Maclaren, who has described this section, records his opinion that the Siwaliks of the Himalayas and the Tipams of Assam were contemporaneous.[191]

The characteristic sandstones of the Siwalik series are strongly developed due north of Dibrugarh, dipping inwards towards the hills.[192]

Abor Hills.—Between the country north of Dibrugarh and the Dihong (Dihang) river in the Abor hills there is an unvisited gap. In the Abor hills area Pleistocene deposits, forming a narrow fringe to the alluvium of the plains, are seen lying upon a core of Siwalik rocks exposed in an outcrop about 4½ miles in width and traversed

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[189] Rec. 18, 122 (1885).
[190] J. A. S. B., 44, 35 (1875).
[191] Rec. 31, 194 (1904).
[192] H. B. Medlicott, Mem. 4, 393 (1865). The elephant tooth picked up in this area is probably that of a modern elephant.

by the Dihong. At Janamukh in the middle of the Siwalik outcrop is a raised terrace of Pleistocene gravels 150 feet thick, the top of it 350 feet above the level of the Dihong[193]. The Siwaliks, occupying the outer and lower foot-hills, dip towards the heart of the main range and are overthrust by Gondwana beds (Damudas). They consist of various kinds of sandstone, the soft micaceous varieties often containing nests of bright lignite. Landslips are very common amongst these rocks.

Mishmi Hills.—Eastwards the Siwaliks enwrap the debouchure of the Sessiri river and form a narrow fringe of soft micaceous sandstones along the foot-hills immediately north and east of Nizamghat where they occupy steep cliffs overlooking the Tangon, as the Dihong is called within the hills.[194] Above them come metamorphic rocks, no Gondwanas intervening as they do in the Abor Hills further west. East of the Tangong, judging from the outline of hills, Siwaliks extend as far as the old Ahom walled city of Bishemnagar, northeast of Sadiya, where the exposure probably ends, since the beds are not found in the vicinity of the Brahmakund; a considerable development of them is seen at Nizamghat at the mouth of the Dihong gorge.[195]

THE MOLLUSCA, FISHES, REPTILES AND BIRDS OF THE SIWALIKS.

The few mollusca which have been found in the Upper Siwaliks belong solely to fresh-water or terrestrial forms. The majority of the specimens obtained are in poor preservation, but all the forms collected from Upper or Middle Siwalik beds have proved to be either identical with living species or closely allied thereto. Amongst those identified, the only land shell is *Bulimus insularis* Ehr., a species which ranges at the present day from Africa to Burma, whilst among fresh-water mollusca the two common Indian river snails, *Viviparus* (*Paludina*) *bengalensis* Lam. and *V. dissimilis* (Mul.) have been recognised, and forms of *Melania, Ampullaria* and *Unio* also occur.[196] In our attempts to correlate the different stages of the Siwaliks with European formations we depend partly upon stratigraphical evidence but chiefly upon the mammalian remains, which have been described under the various subdivisions. The evidence afforded by the remains of reptiles, birds and fishes is of little value, owing to the doubts which surround their stratigraphical provenance and even the localities from which they were collected. The following forms are recorded from the Siwaliks, most of them probably

[193] Gen. Rep. Rec. 42, 81 (1912).

[194] Gen. Rep. Rec. 69, 85 (1935).

[195] J. M. Maclaren, Rec. 31, 193 (1904).

[196] Rec. 15, 106 (1882); Falconer. Palæontological Memoirs, 1, 26, 181 (1886).

from the Upper division and from either the Siwalik, hills or the Punjab.[197]

PISCES. (all Upper Siwalik).[198]

Carcharias cf. *glaucus* or *gangeticus* (living),
Ophiocephalus sp. (a mainly oriental genus),
Silurid scutes,
Clarias falconeri Lyd. (genus confined to Africa and the East),
Heterobranchus palaeindicus Lyd. (an African genus),
Chrysichthys (?) *theobaldi* Lyd. (genus now characteristic of tropical Africa),
Macrones aor (Buch. Ham.; living today in Indian and Burmese rivers),
Rita grandiscutata Lyd.,
Arius sp.,
Bagarius varrelli (Sykes) a large fish inhabiting today the larger rivers of India and Java.

REPTILIA.

Chelonia,
Colossochelys atlas Falc. & Cautl., a tortoise over 8 feet long,
Other gigantic land tortoises,
Bellia sivalensis Theob,
Bellia theobaldi Lyd.,
Damonia hamiltoni (living),
Hardella thurgi (living),
Kachuga lineata (living),
Kachuga dhongoka Gray (living),
Kachuga tectum (living),
Emyda vittata Peters (living in Ceylon, southern and central India),
Emyda lineata Lyd.,
Emyda sivalensis Lyd.,
Emyda palaeindica Lyd.,
Trionyx sp.,
Chira indica Gray (living in the Ganges, Irrawaddy, the estuaries of the Indian and Malayan coasts, and the Phillippines).

CROCODILIA.

Crocodilus palustris Lesson (living form),
C. *palaeindicus* Falc. from Perim Island has already been listed, p. 1742),
Gharialis gangeticus (Gmel.),
Gharialis hysudricus Lyd.,
Gharialis curvirostris Lyd. (from the Lower Siwaliks of Sind has already been mentioned),
Gharialis leptodus Falc. & Cautl.,
Gharialis palustris (living. See Man. 2nd Ed. p. 368)—Crocodilus,
Ramphosuchus crassidens Falc. & Cautl.

LICERTILIA.

Varanus sivalensis Falc.

OPHIDIA.

Python Molurus Linn.

AVES (extremely few, as in most ossiferous formations, and generally fragmentary),
Pelecanus cautleyi Dav. (very close to the modern Pelican P. *mitratus*),
Pelecanus sivalensis Dav.,
Phalacrocorax sp., (a cormorant),

[197] Pal. Ind. Ser. 10, Vol. 3, Nos. 4, 6, 7, 8 (1884-1886).
[198] R. Lydekkar, Rec. 20, 69 (1887).

Leptoptilus falconeri (A. M.-Edw.) a large stork; a genus at the present time confined to W. Africa, and the Indo-Malayan region,
A goose close to or identical with *Mergus*,
Struthio asiaticus A. M.-Edw.,
Dromaeus (?) *sivalensis* Lyd. (an emu doubtfully referred to the living genus).

Referring to the ostrich, Lydekker remarks that it must once have ranged through Persia and connected its present habitat—Syria and Africa—with its old Indian home. The fish fauna has strong African affinities.

The few fresh-water molluscs, fishes and tortoises found in the Siwaliks are all such as inhabit streams. From this and other intrinsic characters, it is unquestionable that the Siwaliks include fluviatile sediments. From the obvious unity, not only of the whole Siwalik series but of the complete Murree-Siwalik sequence, the inference follows that the beds throughout were formed under very similar conditions, while the very close resemblance between the Upper Siwalik beds and the Recent deposits of the Indo-Gangetic plain leaves little room for doubt that the former were deposited subaerially by streams and rivers. The transition from a marine gulf to a river valley must have been characterised by an intermediate phase of salt or brackish water lagoons, and the riverine tract which afterwards took their place, was no doubt varied from time to time by transient fresh-water lakes and swamps. The lagoonal period appears to be represented by the Chharat and corresponding beds, and included brief reversion to marine or estuarine conditions. There appear to be no grounds for assuming that the Murree period was a continuation of this lagoonal phase. The ferruginous character, as shown by the conspicuous red coloration which in the lower part of the great Murree-Siwalik succession forms an unmistakable feature from Garhwal to the Indus and across this river into Kohat, is no longer regarded as evidence of a purely lagoonal type of sedimentation, but as pointing to the probable presence of neighbouring lateritic soils (see p. 1675).

GENERAL CONSIDERATIONS REGARDING THE SIWALIK FAUNA.

Throughout the Upper Tertiary tract of northern and northwestern India there is the same homogeneous mammalian fauna, with a wonderful wealth and variety of form, especially of the ruminants. including several species of the Giraffidae and of antelopes. Recently several rodents have been described but we know little of the smaller mammals as a whole; very few animals inferior in size to a pig or sheep have left any remains, but it is only reasonable to infer that the ancestors of the present rodents, insectivores, bats and other small mammalia lived in the same profusion as they do today. Comparing like with like, especially among the *Carnivora*, *Proboscidea* and *Ungulata* which are all represented and, with the exception of the *Proboscidea* well represented, in the living fauna of India—indeed

better than in most other parts of the modern world—it is impossible not to be impressed with the comparative poverty in variety of the existing mammalian types. The Siwalik carnivores, for instance, are more numerous than the living forms of similar size in the same area, while the ungulates exceed their living representatives in number in the proportion of about five to one, there being something like 100 known Siwalik species and only eighteen Recent. No less than fourteen extinct elephants and mastodons and two dinotheres are represented by a solitary living form. Even such modern types as oxen and buffaloes have dwindled from eight to two. After making allowances for the fact that many of the Siwalik forms belong to differnt epochs of the period, the superior wealth of the Siwalik fauna, when compared with that of today, is both generic and specific. This great impoverishment of the Recent mammalian fauna is not peculiar to India, but is found in other parts of the Old World as well as in America, wherever animal remains have been preserved in sufficient quantity amongst the later Tertiary deposits to enable a just comparison to be made. In the words of Wallace, who was the first to suggest that this enormous reduction in the numbers of the larger mammals was due to the glacial epoch, "we live in a zoologically impoverished world, from which all the largest and fiercest and strongest forms have recently disappeared".[199] W. D. Matthew remarks that India and the East in general are characterised by the survival of many primitive types of mammals, as well as by the absence, scarcity or recent appearance of some of the most progressive and specialised forms thereof.

The Siwalik fauna is closely similar to that found in the Miocene and Pliocene of southern Europe, northern Africa, central Asia and China; to these countries we shall probably have to add Burma and Malaysia. Stage by stage the fauna of these regions can be paralleled in the Gaj and Siwalik deposits of northern and northwestern India. The similarity of the fauna has been more marked at some periods than at others. Thus the resemblance betwen the Lower Miocene (Burdigalian) mammalian faunas of India, Europe and northern Africa is so close as to point to a much freer land communication between India and these regions than at any other period. During the Middle Miocene this intercommunication would appear to have ceased to a large extent, since the species left in India and Europe seem to have pursued independent courses of evolution. This is shown in several ways which have been enumerated by Pilgrim.[200] In the first place the anthracotheres became extinct in Europe before the Middle Miocene, while in India they persisted in the specialised tetraconodont merycopotamine branch. Secondly, in the case of the Suidae, while *Conohyus* is the last representative of this line in Europe, not persisting beyond the Middle Miocene, its successors, *Tetraconodon* and *Sivachoerus*, evolved from it in India. The hyotheroid branch of the Suidae developed the genera, *Dicoryphochoe-*

[199] "Geographical Distribution of Animals", I, p. 150.

[200] Proc. 12th Ind. Sci. Congr., 214 (1926).

rus, Potamochoerus and *Sus* which in Europe are only found as migrants at a later date. Meanwhile Europe produced a special type of its own in the large *Sus erymanthius,* for which Pilgrim has suggested the generic name, *Microstonyx.* Amongst the Proboscidea, the Lower *Miocene forms, Hemimastodon* and *Trilophodon angustidens,* have been shown by Hopwood to be widely present in Europe, Africa and India. The Middle Miocene proboscids of Europe and India display an entirely different development. The zygolophodont type, abundant in Europe, is unknown in India, while the choerolophodont and stegodont branches were exclusively evolved in India and only began to spread to other parts of the world in the Pontian epoch or later.

The ubiquitous Lower Miocene genus, *Dorcatherium,* though persisting alike in Europe and India into the pontian developed in the latter country alone the special lineage of *Dorcabune.* Similar parallel developments can be discerned in the case of the Felidae, the Ursidae, the Mustelinae, the Mephitinae and the Lutrinae. The isolation of India during the Middle Miocene has no doubt been responsible, as Pilgrim remarks, (private communication) for the curious persistence in that region of many ancient types which vanished long before from other parts of the world. The most remarkable instances of this are found in the persistence of the hyaenodonts in the Chinji as *Dissopsalis,* of *Hyaenaelurus* into the Kamlials, of proaelurines into the Chinji and Nagri as *Vinayakia* and *Mellivorodon,* and of *Palaeochoerus* into the Dhok Pathan beds of Piram (Perim) island. Blanford, Lydekker, and more recently Matthew, have indeed remarked on the survival even today of many primitive types of mammals in India and other parts of the oriental region. This character the Indian fauna shares with that of Africa, though in the case of the former, factors other than that of mere survival may have contributed to the result; perhaps the chief of these was the glaciation of the Holarctic region in Pleistocene times.

During the Pontian epoch free communication between Europe, India and China was resumed, and the distribution began in the upper Miocene types which had been evolving apart in these areas. In the opinion of Pilgrim the sudden faunal change which came over Europe in the Pontian was due to the restoration of free access to Europe from Asia for the hordes of animal life which had been developing in the latter continent during the Upper Miocene; the most important member of this fauna was the primitive horse *Hipparion,* to which allusion has already been made. In addition according to Pilgrim, it included the giraffes, the capreoline Carvidae, many groups of the Bovidae such as the musk oxen, the gazelles, the aberrant, goat-gooted boselaphine, *Tragocerus,* the hippotragine and tragelaphine antelopes and the caprine Oioceros, as well as India Boselaphinae of the type of *Strepsiportax* and primitive buffaloes. Among the migrants were also many Carnivora, such as the hyaenas, the ictitherines, which are a curious aberrant branch of the Viverridae, the feline type, *Paramachaerodus* and, arriving perhaps some-

what later, the true dogs and cats. These types, which began to invade Europe before the end of the Sarmatian and for a time dominated the fauna in the southern parts of that continent, appear to a great extent to have passed on into African; the latter country has remained till today their home, whereas all traces of them seem to have vanished from Europe before the close of the Pliocene period.

The resemblances between the Dhok Pathan fauna of India and the faunas of the Pontian of Europe and China are closer than those which any other of the Indian Siwalik faunas bear to the corresponding fauna of these two regions, with the exception of the Lower Miocene. Even so, the species in the different regions are seldom identical, and the genera also frequently differ; in later periods the faunas diverge even more. It is noteworthy that the Pontian fauna of China is closer in its affinities to that of Europe than it is to that of India, a result probably of the rise of the Himalayan range which, as early as the Miocene, had attained an elevation sufficient to make it a partial barrier to the migration of most mammals except the larger Carnivora, elephants and oxen. This barrier became still more effectual in the Pliocene and Pleistocene by the further rise to loftier heights of the Himalayan ranges, and the comparative isolation faunistically of the Indian region at the present day is a fact fully recognised by zoologists. The obstacle to migration across the mountain ranges was probably climatic rather than physical; in any case the routes traversed by migrants in either direction are likely to have been by way of Persia or the Burmo-Chinese frontier. As Professor Morley Davies points out, the meridional trend of the Himalaya made it a very effective barrier, in contrast to the N.-S. direction of the Andes, where faunas could reach lower latitudes by climbing.[201]

As in other parts of the world, the Pleistocene in India is marked by the wholesale extinction of land mammals, a result no doubt of the revolutionary character of this epoch, with violent fluctuations of climate. As examples the highly specialised genera, *Tetraconodon* with its enormously devloped pre-molar teeth, and the huge four-horned *Sivatherium* differed widely from any thing now existing and have left no descendants.

There is no other part of the world in which the anthrapoid apes are represented in such numbers and variety as in India, and the inference follows that the original centre of distribution of the group could not have been far from northern India. Possibly they came from the west by way of Egypt and Arabia. From the whole of the Siwaliks over eighty specimens have been classified under the headings of four genera, and about ten species by W. K. Gregory, G. E. Lewis and M. Helman, of the United States.[202] The Nagri stage of the Middle Siwalik, and in particular that portion of the stage exposed at the locality of Haritalyangar in the Simla hills has yielded them in great profusion. The Indian forms originally referred

[201] "Tertiary Faunas", 1935.
[202] Rec. 72, 467-468 (1938).

to the European genus *Dryopithecus*, which must have been near the starting point of the three modern genera of the gorilla, chimpanzee and orang-outang, have been distributed by Lewis amongst the four genera, *Sivapithecus*, *Sugrivapithecus*, *Bramapithecus* and *Ramapithecus*. The Proboscidea almost certainly originated in Africa, although India ultimately became what Pilgrim calls the great centre of adaptive radiation for the Pliocene forms comprised in the two groups of *Stegodon* and *Elephas*.

The Anthracotheriidae existed in India to an extent which is found nowhere else in the world. They dominate the fauna of the Pondaung Sandstone of Burma, which is assigned to the Upper Eocene, as they do the later Bugti fauna of the Lower Miocene. Pilgrim believes that the family originated in central Asia from some member of the helohyid group but that the earliest adaptive centre of the family, and certainly of the *Anthracotherium* section thereof, lay to the south of the central Asiatic plateau; thence proceeded migrants which were destined to give rise to genera like *Bothriogenys* of the north African Oligocene, and *Brachyodus* and *Ancodus* of the Oligocene and lower Miocene of Europe and the Bugti hills of Baluchistan. India is believed to have been the adaptive centre of the tetraconodont forms exemplified in the Bugti genera *Gonotelma*, *Hyoboops* and *Telmatodon*, and culminating in *Merycopotamus*, which survived until the Upper Pliocene in India and has been found as a migrant in deposits of a similar age in Tunis.

The giraffoid affinity of *Progiraffa exigua* from the Bugti stage of Lower Miocene age is unproven, so that the oldest remains which are with certainty attributable to the Giraffidae, occur in the Sarmatian beds of China as a species of *Palaeotragus*, and in the Chinji stage of the lower Siwaliks, which Pilgrim regards as at latest Upper Tortonian or Lowest Sarmatian, as the aberrant four-horned palaeotragine, *Giraffokeryx*. Matthew and Pilgrim concur in regarding the family as descended from one of the palaeomerycines, probably in central Asia, and Bohlin and Colbert have demonstrated the affinity of *Giraffokeryx* to *Palaeotragus*. Pilgrim admits the truth of this but considers that the obvious specialisation of *Giraffokeryx* beyond the Palaeotraginae of China, both as to horn and teeth, suggests that it was ancestral to the large branching-horned sivatherines, which occur in the Pontian of Europe as *Helladotherium* and in the Dhok Pathan stage of India as *Bramatherium* and *Hydaspitherium*.[203] Matthew sees nothing more primitive in the Chinji Giraffidae than Pikermi can show. *Helladotherium* is, however, much larger than *Giraffokeryx* of the Chinji, and if, as Bohlin thinks, it is a sivatherine, then it is more closely allied to *Hydaspitherium grande* than to *Giraffokeryx*. It is noteworthy that the Palaeotraginae are the most primitive of the giraffoid groups and that, except for *Giraffokeryx*, they are not found south of the Himalaya, although they migrated to Europe in the Pontian. The genus, *Giraffa*, plentiful in the Dhok Pathan, survived into the Pinjor stage of the Upper Siwalik. *Sivatherium*, the most

[203] Pal. Ind., New Ser., Vol. 18, 3 (1932).

progressive member of the Sivatheriinae, with huge branching horns, is exclusively Upper Siwalik and found in the Tatrot as well as in the Pinjor stages; it semes to have migrated into central Africa in the Pleistocene. In India the Giraffidae became comparatively numerous in Middle Siwalik times, scarce in the Upper Siwalik, and later on extinct. Remains of extinct species of giraffe have been found in Greece, Hungary, Persia and China, as well as in India, but the family is now exclusively African.

Colbert suggests that the pigs and peccaries originated in Eurasia, but Pilgrim thinks it not impossible for the Suidae to have come in the first place from Africa. Although *Camelus* itself has not been recognised with certainty, the Camelidae are undoubtedly of North American origin and are found in the Eocene of that country; they are thought to have migrated first to central Asia and thence to India where they arrived in the early Pleistocene, according to Matthew who bases this conclusion on the fact that the Siwalik *Camelus* is not a primitive species but represents a stage of evolution in the dentition attained in North America only at the beginning of the Pleistocene period.

In the opinion of Pilgrim the Bovidae originated in central Asia, which was undoubtedly the adaptive centre of those sub-families nearest to the root forms, namely the Gazellinae, Caprinae, Ovibovinae and Antilocaprinae.[204] The last named sub-family is only known from North America while, except in the case of the Gazellinae, the others did not cross the Himalaya into India until the Upper Pliocene; the Ovibovinae did not cross at all, though they took a prominent part in the Asiatic invasion of Europe in the Pontian. Since the earliest members of the group of Bovidae which is made up of the above four sub-families and is known as the Aegodontia, are already highly specialised in the Sarmatian, Pilgrim assumes that they were differentiated at least as early as the Helvetian, the Gazellinae reached India in the Chinji epoch; previous to this the most primitive form of boodont antelope, the so-called *Eotragus,* is known from the Helvetian of Sansan and Tanganyika. Pilgrim thinks that the most likely centre of distribution for the various sub-families belonging to the boodont group of the Bovidae lay between Persia and Africa. Various branches of the Boselaphinae are represented in the Chinji stage of India in the form of the genera, *Helicoportax, Strepsiporitax* and *Sivaceros;* the two last-named genera, or genera believed to be allied thereto, occur rarely in the Sarmatian of Europe. A primitive tragelaphine, *Sivoreas,* also occurs at Chinji. Boselaphinae which seems to be descended from the Chinji forms dominate the antelope fauna of the Dhok Pathan, but with the exception of the abiquitous *Tragocerus* these are not found in the European Pontian. The Dhok Pathan stage contains in addition primitive members of the Reduncinae and Hippotraginae; the Latter sub-family is plentiful in the Pontian of Europe, together with the Tragelaphinae, which have not been recognised in the Dhok Pathan. The only remarkable

[204] Pal. Ind., New Ser., 26, Mem. 1, 25 (1939).

group of the gazellines besides *Gazella* which is known as fossil is that of which the sole surviving representative is the Indian Black Buck, *Antilope cervicapra;* this was represented by *Helicotragus* and *Protragelaphus* in the Pontian of Europe, possibly by *Antilospira* and *Siprocerus* in China, and by certain little known forms from the Dhok Pathan and the Tatrot in India. An indirect descendant of Protragelaphus exists in the widespread Villafranchian antelope, *Gazellospira torticornis.*

The descent of the Bovinae from one of the Boselaphinae has been established beyond doubt. The earliest known undoubted bovines occur in the Pontian of Europe as *Parabos* (?) *macedoniae,* and in the Dhok Pathan of India as *Proamphibos* (?) *hasticornis* and cf. *lachrymans.* The two genera, *Parabos* and *Proamphibos,* primitive and closely allied buffaloes, occur in the Astian of Montpellier and the Tatrot stage of India respectively. The latter, in Pilgrim's opinion, is the direct ancestor of *Hemibos* found in the Pinjor stage of India and of *Bubalus.* In addition to these, another primitive bovine, *Proleptobos,* is known from the Irrawadian series of Burma, in what is believed to be a Dhok Pathan horizon ; this is ancestral to *Leptobos* of the European Villafranchian and the Pinjor stage of India, and may have given rise to the Taurina generally, including the true oxen as well as the *gaur* and the bison. After the Proboscidea, the Bovinae dominate the fauna of the Pinjor, and include in addition to *Hemibos* and *Leptobos, Bucapra, Platybos, Bubalus, Bison* and *Bos.* These genera are represented by species which are more primitive than any found elsewhere ; for this and other reasons Pilgrim is convinced that India was at least a part of the adaptive centre of the Bovinae, succeeding waves of migration from that country being responsible for the oxen and buffaloes of the world.

The early evolutionary stages of *Hipparion* and of the horse are especially well represented and gradational in North America where, the conclusion seems inevitable, that the evolutionary changes proceeded from the Upper Oligocene *Miohippus* through the Lower Miocene *Parahippus* to the later Miocene *Merychippus.* From the latter genus it has been concluded that *Hipparion* evolved along one branch and *Equus* along another, thus:

$$
\begin{array}{ccc}
 & & \textit{Equus} \\
 & & \uparrow \\
 & & \textit{Plesippus} \\
 & & \uparrow \\
\textit{Hipparion} & & \textit{Pliohippus} \\
\uparrow & & \uparrow \\
 & \textit{Merychippus} & \\
 & \uparrow & \\
 & \textit{Parahippus} & \\
 & \uparrow & \\
 & \textit{Miohippus} &
\end{array}
$$

That these further modifications also took place in America is also inferred, since there are many intermediate stages, not only between *Merychippus* and *Equus* but also between *Merychippus* and

Hipparion. The American writers claim that the *Hipparion* and *Equus* found in the Siwaliks of India are in each case migrant forms from America. According to Pilgrim, *Hipparion* and *Equus* severally make their appearance earlier in India than they do in North America and therefore cannot as such be migrants from the later country. He prefers to conclude that this invasion of Asia took place earlier than the Pliocene and that the migrant form was an unknown ancestor of *Hipparion*—perhaps a primitive *Merychippus*—which had come presumably from America but which had one adaptive centre of dispersal somewhere in central Asia. From this centre *Hipparion* is supposed to have arrived in India in Tortonian times, and *Equus* in the Montpellierian stage of the Pliocene. Meanwhile the American species of both *Hipparion* and *Equus* are presumed to have evolved independently and less rapidly in North America. Such a close parallel evolution along two branches is admittedly unusual and is the chief or only objection of the American authorities to Pilgrim's scheme of classification.[205] Deposits similar to the Siwalik fill all the great river valleys of eastern Afghanistan. In central Tibet, the continental sandstones and conglomerates above the Cretaceous have been much involved in the folding; the youngest of these are horizontal conglomerates with mammalian remains ascribed by Hennig to the Pleistoncene.

The origin and life-history of the Siwalik river are bound up closely with those of the Himalaya and will be further considered under that heading.

II. The Tipam Series of Assam.

Distribution and subdivision.—The moderately coarse, ferruginous, massive or current-bedded sandstones of the Tipam series or facies are described by Evans as strikingly different from the Surma beds which they succeeded.[206] This contrast in lithology, and the fact that the Tipam beds from place to place rest on different members of the Surma or Barail series, beget a suspicion that the boundary between them is an unconformity, marking the change from marine or estuarine to fluviatile conditions. The Siwalik outcrops already described in the foot-hills at the extreme eastern end of the Himalaya have been traced with no very long interruptions round the head of the Assam Valley, and there seems little doubt that the Tipam series of southeastern Lakhimpur is continuous beneath the Brahmaputra alluvium with these Siwalik deposits along the northern border of the district.[207] Not only is this the case but, across the country of the Singphos, it is with equal probability continuous with the Irrawadian beds of the Hukawng valley in Upper Burma. In the

[205] G. E. Pilgrim and A. T. Hopwood, Rec. 73, 437-482 (1938); Proc. 12th. Ind. Sci. Congr., 213 (1925); W. D. Matthew. Bull. Amer. Mus. Nat. Hist., Vol. 56, 439-440 (1929); E. H. Colbert, Amer. Mut. Novit, No. 797 (1935).

[206] Trans. Min. and Geol. Inst. Ind., Vol. 27, 206 (1932).

[207] Gen. Rep. Rec. 32, 150 (1905). The Siwaliks of the Himalayan foot hills north of Dibrugarh have been described by Maclaren as Tipam sandstones of characteristic nature (Rec. 31, 191-195; 1904).

Patkoi Hills the Tipam series reaches an elevation of 7,000 feet and is described as having obliterated completely older rocks.[208] From the extremity of the Lakhimpur disrtict, the Tipam outcrop extends continuously but for alluvial interruptions south-westwards through the Naga hills, where it forms a prominent element of the outer ranges, through the hills of north Cachar, where it appears in a few synclinal areas, to the Surma valley of Sylhet and westwards to the Garo Hills; in the latter area it forms a large part of the Upper Tertiaries which along the Someswari have widened to a zone 14 miles across. From Cachar the outcrop fringing the eastern side of the old gulf stretches through the Lushai Hills and Hill Tippera to Chittagong. The total length of the outcrop, omitting alluvial interruptions, from Lakhimpur to Chittagong is well over 600 miles. From their correlation with the Siwaliks, as well as from their position above the Surma series, the Tipam beds should correspond to the Pliocene (including the Pontian), though it is possible that in the uppermost parts of Assam they transgress downwards into the Burdigalian.

Evans has divided the series into three stages, of which the middle or clay stage corresponds in general character with the Middle Siwaliks. Over them lies a fourth formation, the Dihing, which the author would prefer to include within the Tipam series, the classification of which would then correspond closely with that of the Siwalik as follows:

Tipam series	Upper	Dihing stage Num Rong Khu stage
	Middle	Girujan Clay
	Lower	Tipam sandstone

The Num Rong Khu stage is of limited occurrence in Upper Assam, but further south has been recognised with some degree of probability; in the Surma valley the Dihing beds are also of limited distribution.

Tipam Sandstone.—The Tipam Sandstone stage in the Surma valley, between 3,000 and 5,500 feet in thickness, is composed mainly of moderately coarse, occasionally gritty, thick-bedded ferruginous sandstones, bluish or greenish in colour when fresh but weathering to orange or brown; the greenish colour is due to the presence of chlorite.[209] Research on the question of heavy mineral residues by the Burmah Oil Co.'s staff shows that the Tipam sandstone possesses a rich assemblage, including: ilmenite, magnetite, epidote, staurolite, kyanite, hornblende, garnet, chloritoid, zircon, rutile, tourmaline, and in smaller quantities, tremolite, actinolite, enstatite, zoisite and andalusite. Some sections are said to be almost free from argillaceous beds but more frequently the sandstones are characterised by shale partings and there is usually a moderate proportion of more or less sandy shale as well as alternations of thin laminae of

[208] J. M. Maclaren, Rec. 31, 192 (1904).
[209] J. M. Maclaren, Rec. 31, 191 (1904).

coarse sand with shale or clay. Mottled clay is occasionally seen, while beds of grit, conglomerate and shale conglomerate occur in some areas. The argillaceous bands when broad enough are often marked by long narrow valleys. Fossil wood is abundant in a few localities such as the Chargola valley in Sylhet, and lignite is quite common; beds probably assignable to the Tipam sandstone in the Garo Hills have yielded specimens of fossil wood belonging to the *Dipterocarpaceae.*[210] In the Bhuban Hills the Tipam Sandstone stage shows much lateral variation. The maximum thickness of 5,500 feet is seen in the hills between the Chargola and the Longai.

Some 24 miles of alluvium separate the exposures in the Surma valley area from those around the head waters of the Langting and Dhansiri on the southern borders of the Naga Hills district. Thence the outcrop is continuous for 200 miles to the oilfield of Digboi except for a short alluvium-filled gap near Safrai; in addition to this principal outcrop there are several long narrow strips of the Tipam Sandstone stage exposed by strike faults.

In the Naga Hills district the stage has increased in thickness to 5,900 feet near the confluence of the Bhagti with the Dayang, and to 6,700 feet to the north of the Dayang; the sandstones of this area sometimes contain a considerable amount of calcareous cementing material and, occasionally, very thin bands of a very impure limestone, in addition to the usual argillaceous intercalations. The sandstones show the usual ripple-marking and current-bedding as well as small local unconformities. Local patches of ferruginous matter probably mark the resting place of fossilised tree-trunks;[211] streaks of lignite associated with iron-staining are evidently the remains of branches of wood.

Further northeast the stage becomes more argillaceous and thiner. In the Jaipur anticline of Lakhimpur, where it has reached a minimum thickness of little more than 3,000 feet, it is characterised by a maximum argillaceous content, the middle sandstones of the stage giving place to alternating lenticles of blue and mottled clay, mudstone, shaly sandstone and sandstones. Grits and fine conglomerates occur at or near the base of the Lower arenaceous portion, which is locally known as the Barjan sandstone. Evans remarks on the extremely well marked lateral variation of the members of the stage in this anticline, beds thickening and thinning, disappearing and reappearing in a bewildering fashion.

The Tipam sandstones in the Mikir Hills are described as containing abundant silicified wood, some of the trunks being four or five feet in length. In this area also the stage is characterised by veins of hematite.[212]

East of Jaipur the Tipam stage reappears near Ledo and stretches thence eastwards in the form of a broad tract into the country of the

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[210] K. A. Chowdhury, Rec. 73, 247-265 (1938).

[211] E. H. Pascoe, Rec. 42, 256 (1912).

[212] F. H. Smith, Mem. 28, 92 (1898).

Singphos, where it occupies high hill ranges interrupted by magnificent ravines. In the Tipam river the stage is some 3,300 feet in thickness.

Excluding the silicified wood and indeterminate vegetable remains, very few fossils have been recorded from the Tipams and these are probably from the lower stage of the series, though this is not certain. Near the confluence of the Bhagti and Dayang the Tipam Sandstone stage has yielded a new species of *Batissa,* closely related to *B. crawfurdi.*[213] A fossil fruit from the Tipams of Cachar has been identified as belonging to one of the *Juglandaceae.*[214] Lastly, between the western extremity of the Garo Hills and the Brahmaputra, in line more or less with the fossil localities of Bagmara and Dalu and situated betwen the Kalu river and Karaibari (Mahendraganj) and probably nearer the latter town, are some sandstones and clays which are exposed at low water; from these several badly preserved fossils are recorded as having been collected in by-gone days and as consisting of both marine, land and fresh-water forms. It is not unlikely that the marine forms on the one hand and the land and fresh-water forms on the other come from different geological horizons. The horizon of the former may prove to be the same as that of the Boka Bil fossil beds of Dalu and Bagmara (p. 1679), while the terrestrial and fresh-water fauna, which includes *Anthracotherium (Microbunodon) silistrense* Pentl. and *Chaeromeryx silistrensis* Pentl., both Lower Siwalik species, obviously belongs to the Tipam series and most probably to its lower stage.[215] The former species has an extensive vertical range. In the beds above the mammal-bearing horizon fossil wood has been observed.[216] Allowing for the effect of a much higher rainfall, the Tipam, sandstone stage has many of the characters of a less highly coloured equivalent of the Kamlial stage of the Lower Siwaliks.

Girujan Clay stage.—The Girujan stage, by its distinctive argillaceous character, provides a useful marker in the delimitation of the Tipam series and its stages. The ground it occupies is invariably lower-lying than the hills formed by the underlying Tipam sandstones. As a rule it is not completely flat, and the sandstone bands of the stage, when particularly hard, stand out in narrow ridges which may be of considerable height; nevertheless, Evans notes, the highest of these ridges does not attain an elevation equal to that of the scarp formed by the underlying Tipam sandstone. Of the Siwalik stages the Girujan most resembles the Chinji, of which it might be a less ferruginous representative, but, in the absence of any vertebrate fauna, its precise equivalent in the Siwalik sequence cannot be gauged with any certainty.

The chief feature of the Girujan stage is the predominance of mottled clay. In the Surma valley, where the thickness is a little

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[213] Gen. Rep. Rec. 61, 19 (1928).
[214] Gen. Rep. Rec. 61, 18 (1928).
[215] Man. 2nd Edit., 332-333 (1893).
[216] E. Vredenburg, Rec. 51, 331 (1920).

under 3,000 feet, the rest of the stage is made up mostly of pink, reddish or mottled sandstone. In Cachar the Girujan beds, about 6,000 feet thick, are seen in most cases dipping gently in broad synclinal valleys, of which the Jalinga is a good example; here a considerable amount of ferruginous material is present, and the clays are often sandy and less frequently mottled. Forty miles northeast of the exposures in the Dikcha valley Girujan beds are again seen in the Dhansiri valley, whence another strip of these rocks, occupying low ground and largely masked beneath boulder debris from the adjoining Barail range, stretches north-eastwards for 50 miles. Several other strip-like outcrops are seen in the western part of the Naga Hills district, the clays faulted against the Barail rocks on one side and overlying the Tipam Sandstone stage on the other; here the Girujan beds, some 6,000 feet thick, are more argillaceous than they are elsewhere. There are many large exposures of this stage near Jaipur and Digboi and in the Frontier Tracts; in the latter region the thickness given by Evans is about 4,000 feet. Near Digboi the lower stage of the Tipam series can be seen passing up gradually into the Girujan. In this region, red, brown, purple and blue mottled clays are most common, but in some places a very characteristic pink and white clay is recorded. Here the stage includes, especially in its lower part, moderately thick beds of ferruginous sandstones which closely resemble those which bulk so largely in the Tipam Sandstone stage and contain much the same accessory minerals. The sandstone higher up are usually finer in grain, somewhat greenish in colour, and contain more argillaceous impurities. In the Dihing section the Girujan stage has thinned out to a minimum of 2,600 feet in spite of the fact that, here as well as in the neighbouring Disang section it exhibits its more arenaeous development; a very characteristic feature of the Girujan stage is the occurrence in quantity of mottled sandstones of a purplish colour, rarely seen in the Tipam Sandstone stage. Lignite, silicified wood or wood partly silicified, and partly carbonised, occur but are not noticeably common. Both the stage as a whole and their individual beds show lateral variation.

Num Rong Khu stage.—In the Dihing river above Jaipur, the Girujan clays are overlain by a stage which is mainly arenaceous and contains beds of lignite conglomerate. In the lower portion of this Num Rong Khu stage the sandstones, usually soft and in some cases not indurated beyond the stage of sand-rock, are somewhat fine in grain and usually of a greenish blue colour. In the upper portion, where the rocks are coarser, this distinctive colour is less striking and is replaced by a blue-grey or whitish grey, weathering to orange or brown. Beds of grit or gritty conglomerate are very common, especially in the upper portion of the formation. These beds are composed largely of quartz grains of the size of a small pea embedded in a sandy matrix; small sandstone pebbles occur rarely, but in the coarser beds small fragments of red jasper are of common occurrence. Beds of clay more or less sandy and some of the mottled green, grey and brown, sometimes with reddish and purple bands, occur at intervals throughout. The most distinctive feature of the stage is the

occurrence of lignite pebbles. If these pebbles were derived from the underlying Coal Measures, the fact that they are composed of lignite and not of true coal such as that now seen in the Coal Measure seams, it would follow that erosion of the latter must have taken place before the material hardened to coal.[217] Evans is of opinion that they were the product of contemporaneous erosion and not derived from the coal material of the Coal Measures. The grits usually contain pebbles and fragments of lignite in abundance and a few large irregular lenticles of the same material. Most of the sandstones contain small fragments of lignite and, especially in the case of the higher beds, large pebbles, either scattered throughout the rock or arranged in definite layers to form a lignite conglomerate. Fossil wood occurs, silicified internally with a carbonaceous crust.

North of the Dihing, near Miao, the Num Rong Khu stage forms a considerable range of hills known as the Num Rong Khu or Mana Bum. About 3,300 feet of the beds are exposed in this anticlinal area without the base being seen; the softness of the rocks is the cause of frequent landslips. This stage is probably not seen in the Mikir Hills.[218] In the Safrai and other streams of the Naga Hills the Num Rong Khu beds take the form of sandstones with numerous pebbles of lignite, overlying the Girujan Clays. In Cachar the stage appears to be either absent or represented by an arenaceous development of the upper part of the Girujan. In Sylhet its place is taken by what Evans calls the Dupi Tila beds, named after the lines of hills near Jaintiapur. The thickness here, including some unexposed and probably argillaceous beds, must be about 2,500 or 3,000 feet, the exposed portion consisting almost entirely of coarse ferruginous sandstones with numerous layers of quartz pebbles; in the Sylhet plain the coarse ferruginous sandstone is accompanied by other coloured sands, the beds forming several groups of low hills. This stage occurs as far west as the Jadukata river in the Khasi Hills.

Dihing stage.—Above the beds just described comes a great thickness of pebble beds to which Mallet gave the name of Dihing series. An unconformity or overlap is suspected at its base, where there is an abrupt change in lithology, but there is little doubt that it is the equivalent of the uppermost Siwalik stage—the Boulder Conglomerate—which is now known to be of Pleistocene age. In some parts of the Naga Hills this pebble stage with its interbedded clays rests directly on the Girujan Clays; elsewhere in the district the Num Rong Khu beds intervene. At Binnakandi in Sylhet it overlies what may be the Dupi Tila (Num Rong Khu) beds but in other parts of the district it rests on the Girujans. Since they represent a continuation of the fluviatile sedimentation in the Assam valley, there appears to be no serious objection to the inclusion of the Dihing beds as the topmost members of the Tipam series.

In the type area of the Dihing river, this stage comprises 800-1,000 feet of alternations of pebble-beds and beds of soft clay, indistinguish-

[217] J. M. Maclaren, Rec. 31, 192 (1904)
[218] F. H. Smith, Mem. 28, 92 (1898).

able from recent alluvium. The pebble-beds, each of them usually about a hundred feet in thickness, are loosely compacted, and the heavy minerals detected in the well-rolled pebbles show that the latter are derived from the Barail and not from the Disang sandstones as Mallet suggested. Associated with these conglomerates are blue sandy clays containing sporadic pebbles and, except for their colour not unlike the brown and red clays of the Upper Siwaliks of north-west India. Fossil wood is common in these beds.

In the Mana Bum range, further northeast, where the Dihing stage exceeds 5,000 feet in thickness, the pebble-beds frequently contain lenticles of soft sand. Towards the base of the sequence in this area the pebble-beds become thinner and the pebbles smaller, the lowest portion of all, according to Evans, consisting of very soft, greenish and somewhat argillaceous sandstone with comparatively few layers of pebbles but with occasional beds of sandy clay. The prevailing rock of which the pebbles in this area are composed is a soft decomposed gneiss, the loose sands at the same time being largely made up of gneissic debris. Coarse loose sands with occasional pebble beds have been met with in borings drilled by the Assam Oil Co. in the hills southeast of the Brahmaputra alluvium. In Cachar the Dihing stage has a thickness of about 2,000-3,000 feet and near Binnakandi is seen dipping at about 50°. Here the pebbles are composed of quartzite and sandstone, often stained red and embedded in a matrix of red sand.

The Tipams in Chittagong.—To the Assam gulf belong the Tipams of Chittagong. These sediments, which succeed beds belonging probably to the Surma series, consist for the most part of soft, ferruginous sand-rock, current-bedded, frequently coarse and micaceous, and well displayed in a section in Chittagong.[219] Hard sandstone is occasionally seen and caps the Chandranath ridge above Sitakund. In the lowest horizons are large calcareous sphaeroidal concretions identical with those so characteristic of part of the Irrawadian sequence in Burma. Ferruginous conglomerates are occasionally seen. Fossil wood has so far escaped detection in these beds.

Karikal.—An artesian well sunk in 1884 in the French possession of Karikal on the Coromandel coast of Tanjore brought up one of the richest Tertiary faunas known in India from seven or eight horizons between the depths of 190 and 345 feet. The section, which reached a total depth of a little over 350 feet, consists mostly of alternating sands and clays, both forms showing admixture with each other, a few pebble-beds and conglomerates, and the fossil beds.[220] The fauna appears to be of Pliocene age,[221] in which case the beds may be regarded as belonging to the Assam gulf and as the marine equivalent

[219] E. H. Pascoe, Mem. 40, 312 (1914).

[220] E. Vredenburg, Mem. 32, 57-61 (1901).

[221] E. Vredenburg, Mem. 50, 5 (1925).

of part of the Tipam series. Nearly 100 species have been described by M. Cossmann[222] as follows:

GASTROPODA.

Actaeon (Solidula) solidulus (Linne) (living in the Indian Ocean),
Actaeon (Solidula) cf. *affinis* A. Adams (species living),
Actaeon (Solidula) bonneti Cossm.,
Atys (Alicula) panaulax Cossm.,
Ringicula bonneti Cossm.,
Terebra (Myurella) mariesi A. Smith (living off Japan),
Terebra (Myurella) cancellata Quoy (living),
Terebra (Myurella) cumingi Desh. (living in the China seas),[223]
Terebra (Myurella) cingulifera Lam. (? living),
Terebra (Myurella) karikalensis Vred.,[224]
Terebra (Duplicaria) cf. *anomala* Gray,[225]
Terebra (Hastula) continuicosta Cossm. (living),
Pleurotoma cf. *crispa* Lam.,
Pleurotoma (Hemipleurotoma) cingulifera Lam. (living),
Pleurotoma (Hemipleurotoma) bonneti Cossm. (found also in Cutch and Burma),
Clavatula (Perrona) unisulcata Cossm.,
Surcula javana (Linn.) (living; *S. nodifera* (Lam.),[226]
Surcula streptopleura Cossm.,
Surcula tuberculata (Gray) (*S. punctata* (Reeve),[227] abundant; living),
Mitra (Cancilla) flammea Quoy (living),
Mitra (Cancilla) circulata Kien.,
Latrunculus (Eburna) spiratus (Linn.),
Latrunculus (Eburna) occlusus Cossm.,
Nassa ovum Cossm.,
Nassa (Hebra) bonneti Cossm.,
Nassa (Niotha) gemmulata Lam.,
Nassa (Hinia) karikalensis Cossm.,
Nassa (Hinia) colpophora Cossm.,
Nassa (Telasco) verbeeki Mart. (Pliocene of Java),
Nassa (Amycla) dimorpha Cossm.,
Cymia sacellum (Chemn.), (abundant on the Java coast; including Cossman's "*Melongena proteiformis*"),[228]
Persona (Distortrix) reticulata (Linn.) =Cossman's *R. metableta*,[229],
Hindsia mekranica Vred. (=Cossman's "*H. tjemoroensis* Mart. ?),
*Ranella bituberculari*s Lam. (=Cossman's "*R. karikalensis*),
Cerithium (Vertagus) bonneti Cossm.,
Turritella tjadjariensis Mart. (?= *T. angulata* Sow.),
Crepidula (Siphopatella) subcentralis Cossm.,
Drillia ferenuda Cossm.,
Drillia bonneti Cossm.,
Drillia (Brachytoma) karikalensis Cossm.,
Drillia (Crassispira) sacra Reeve,

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[222] Journ. de Conch., Vol. 48, 14-66 (1900); Journ. de Conch., Vol. 51, 105-173 (1903).

[223] Journ. de Conch, Vol. 48, pt. 2, fig. 14 (1900).

[224] Rec. 51, 345 (1920).

[225] E. Vredenburg, Rec. 51, 344 (1920).

[226] E. Vredenburg, Mem. 50, 38 (1925).

[227] E. Vredenburg, Mem. 50, 38 (1925).

[228] E. Vredenburg, Mem. 50, 228 (1925).

[229] E. Vredenburg, Mem. 50, 234 (1925).

Drillia (*Crassispira*) *sinensis* Hinds, (living in eastern seas),
Drillia (*Crassispira*) *quadricarinata* Cossm.,
Drillia (*Crassispira*) *adelomorpha* Cossm.,
Mangilia (*Clathurella*) *costicrenata* Cossm.,
Mangilia (*Clathurella*) *karikalensis* Cossm.,
Daphnella (*Raphitoma*) *mirostriata* Cossm.,
Conus (*Leptoconus*) *vimineus* Reeve (=Cossman's "*C.* (*Chelyconus*) *subvimineus*),"
Conus (*Leptoconus*) *cosmetulus* Cossm.,
Conus (*Leptoconus*) *bonneti* Cossm.,
Conus (*Leptoconus*) *aulacophorus* Cossm.,
Conus (*Lithoconus*) *malaivus* Hwass.,
Conus (*Lithoconus*) *ngavianus* Mart. (Cossman's "*C. hypermeces*")[230].
Conus (*Lithoconus*) *literatus* Linn., (living in the Indian Ocean),
Conus (? *Lithoconus*) *karikalensis* Cossm.,
Conus (*Dendroconus*) *figulinus* Linn., (living),
Conus (*Dendroconus*) *quercinus* Hwass,
Merica asperella Lam.,
Merica verbeeki Mart.,
Sveltia morgani Cossm.,
Trigonostoma crispatum Sow.
Trigonostoma crispatum Sow.,
Trigonostoma bonneti Cossm.,
Trigonostoma tjibaliungense Mart.,
Oliva (*Neocylindrus*) *mustelina* Lam., (Recent),
Oliva (*Neocylindrus*) *irisans* Lam.,
Olivancillaria gibbosa Born.,
Olivancillaria (*Agaronia*) *acuminata* Lam., (? living),
Ancilla (*Sparella*) *cinnamomea* Lam. (living),
Ancilla (*Alacospira*) *tornata* Cossm.,
Ancilla (*Sparellina*) *candida* Lam.,
Marginella (*Eratoidea*) *bonneti* Cossm.,
Marginella (*Eratoidea*) *karikalensis* Cossm.,
Marginella (*Glabella*) *oligoptycha* Cossm.,
Cryptospira (*Gibberula*) *tectiformis* Cossm.,
Cryptospira (*Gibberula*) *cuneata* Cossm.,
Cryptospira (*Gibberula*) *glandina* (*Velain*) Cossm.,
Surcula (*Turricula*) *lirocostata* Cossm.,
Fusus perplexus Adams.,
Clavilithes inopinatus (Cossm.),
Turbinella pirum Linn. (=Cossman's *T. rapa* Gmel.).
Tudicula spirillus (Linn.), i ? Tudicla,
Siphonalia (*Penion*) *heptozodes* Cossm.,
Cyllene varians Cossm.,
Phos macrostoma Cossm.,
Tritonidea (*Cantharus*) *tranquebarica* (Martini),
Anachis crassicostata Cossm.,
Atilia simplex (Mart.),

This fauna is the equivalent of the Gwadar stage of the Makran series of Baluchistan, and closely related to the Odneg stage of Java, with which it has 16 species in common;[231] the proportion of recent species is 35 or 40 per cent., a close approximation to that of the Java fauna (35-40 per cent.). In this respect it shows just as close a relationship to the Burma Pegu, which has 30-48 per cent., of living forms and is regarded as of Oligocene—Miocene age.

[230] E. Vredenburg, Rec. 53, 137 (1921).
[231] Gen. Rep. Rec. 38, 21 (1909).

III. The Irrawadian Series of Burma.

Terminology.—The highest member of the Tertiary system in Burma was originally known as the "Fossil Wood Group" on account of the abundance of silicified wood which its beds contain. Fossil wood is not confined to this particular formation in Burma but is found occasionally in a silicified as well as carbonaceous condition at more than one horizon not only in the Pegu beds below but even in certain sections of the Eocene; in the post-Irrawadian Plateau Gravels also, rounded boulders of silicified wood derived from the underlying Tertiary group are in places very plentiful. Nevertheless the abundance of silicified wood in the uppermost Tertiary group of Burma is never paralleled in any other geological formation in that country or in India, and the only real objection to the term "Fossil Wood series" is its clumsiness. For this reason a modification of Noetling's substitute, "Irrawaddy Sandstone" or "Irrawaddy System" proposed by writer will be adopted and the beds referred to in this work as the Irrawadian.[232] In past publications they have been frequently alluded to as Pliocene, an unsatisfactory alternative since their lower limit transgresses below the base of the Pliocene, if we include the Pontian in that series and if we regard the Maw Gravels, which are equated with the Kamlial of Helvetian, as part of the Irrawadian series.

Stratigraphical Limits.—Like the Siwalik of northern and north-western India, therefore, the Irrawadian is composed of the sediments of river which replaced a marine gulf. This replacement took place gradually from north to south and seems to have been spread over more than one epoch, the gulf silting up section by section in this direction. The earliest river silts in the north, therefore, differ appreciably in age from the earliest river silts in the south and are considerably older. Were the fluviatile beds more fossiliferous than they are, it might be possible to classify the whole Tertiary sequence of Burma on a more or less true time-scale, but vertebrate remains and fresh-water molluscs are few and far between or at least have not yet been collected in adequate numbers, and for the present, at any rate, the only practical solution of the classificatory problem is to reserve the term Irrawadian for the sediments of this precursor or precursors of the modern Irrawaddy river, and the term Pegu for the marine or estuarine deposits which preceded them. The question has already been discussed (pp. 1687-88), but it is of importance to note that the higher parts of the Pegu series when traced northwards are replaced by Irrawadian river silts of the same age; in some cases an actual lateral passage of the one into the other can be observed. There must at the same time be lateral changes of this kind along east-to-west lines, but these have not so far received much attention. The term, Irrawadian, is in this way used to distinguish a facies or phase rather than a true series or epoch.

[232] Mem. 40, 29 (1912).

Distribution.—The Irrawadian series covers a very large tract in the great synclinorial basin between the Arakan Yoma and the Shan Plateau. This synclinorial exposure is split into two main areas by the flat anticline of the Pegu rocks forming the wide and rolling Pegu Yoma, and is further interrupted elsewhere by numerous smaller anticlinal tracts or domes of Pegu rocks. West of the Pegu Yoma it occupies a large part of the Irrawaddy valley; east of the Yoma it stretches northwards from the northern boundary of Toungoo along the railway line to Mandalay, following first the southwardly flowing Sittang river and afterwards the northwardly flowing Samon or Panlaung. There is rather more clay than usually associated with these beds in the Sittang valley, whilst in two small outlying patches east and north of the town of Toungoo the group is represented by a form of laterite containing numerous pebbles. The series is affected here and there by faulting; in the district of Shwebo it is faulted on the east against the old Mogok series. Much of the central tract of the wide Tertiary synclinorium is characterised by anticlines, some of them tight, faulted and exposing Pegu beds, separated from each other by wide, comparatively flat synclines.

In Upper Burma the beds are extensively developed and occupy large areas, especially between the Irrawaddy and the Chindwin above their confluence. Much of the country further north is a *terra incognita* from a geological point of view, but beds of Irrawadian type have been recognised in northern Myitkyina, in the valley of the Mali Kha, and in the Hukawng valley; from the latter area they probably form a continuous outcrop with the Tipam rocks of the Singpho country and with the same sediments of the Patkoi range.

The occurrence in abundance of fragments of silicified wood far beyond the present limits of the outcrop proves that the present Irrawadian exposures are mere remnants of a formation which once occupied a much more extensive area and was of considerably greater thickness. Judging from the occurrence of the larger blocks of fossil wood alone, and ignoring the small fragments in the alluvial gravels, the beds of this series must once have reached far to the south of their present limits, probably along the whole eastern side of the Arakan Yoma and certainly as far as Rangoon along the Pegu range. In a boring sunk by the Burmah Oil Company at Syriam on the bank of the Rangoon river, gravels were met with at a depth of 220 feet, containing small pebbles of quartz and sandy shale, rarely larger than a pea, numerous fish and reptilian teeth, chelonian and mammalian remains, and silicified wood. These organic relics were found to include: a species of *Carcharias* close to *gangeticus*, pre-Recent members of the Lamnidae, *Oxyrhina pagoda* Noetl., spines and a dorsal vertebra of a siluroid fish, a tooth probably of Myliobatid fish, several reptilian teeth, perhaps of a crocodile, chelonian plates of *Trionyx* and *Emys*, a toothless mandible of a small mammal, possibly one of the Cheiroptera, and a portion of the dorsal vertebra of an ox. It is of course possible that these fossils are derived forms, but their abundance is more in favour of the supposition that the

Irrawadian is *in situ* under the alluvium. No exposed outlier of the Irrawadian is known further south than Prome,[233] unless we accept Leicester's claim that the rocks of the main ridge south of the small Pegu inlier which is seen at the northwest corner of the Hlawga reservoir twenty miles north of Rangoon belong to the Irrawadian and not to the Pegu. From the study of various borings put down in the neighbourhood of Rangoon, Leicester deduces the presence of an anticline of Irrawadian beds stretching from Pazundaung Creek beneath Rangoon towards Insein in a N. N. W.—S. S. E. direction ; the crest of this fold is said to be well seen in a cutting on Victoria Avenue.[234]

Lithological Character.—Theobald divided the series under consideration into three subdivisions. The middle one, consisting of fine silty clay with a few small pebbles, forms a marked band although not more than 40 feet in thickness,[235] while the other two are composed mostly of sands and conglomerates. Such a classification may be recognisable in Lower Burma where Theobald worked but has not been definitely established further north, though it is quite possible that here too in the more central tracts, clay is somewhat more plentiful in the middle of the sequence than it is above or below. There does appear to be a general tendency for conglomerates and pebble beds to be thicker and more numerous in the lowest and uppermost portions. In Upper Burma the Irrawadian beds, although including in a few places pockets of clay, consist for the most part of deposits of soft sand-rock, always current-bedded, with interstratified brown and red earth beds, some hard sandstones, pebble-beds, gravels and conglomerates. In the more central tracts, around the oilfields, soft sand-rock is by far the predominant type, and gravels and conglomerates are quite subordinate. Along parts of the western flank of the synclinorium, especially in the Man and Mon valleys of south Minbu, in Thayetmyo, and in the country further south, gravel or conglomerate forms a large proportion of the series. Near Mezali in west Minbu the ferruginous conglomerates, with large trunks of fossil wood, are as much as 4,000 feet thick, and only the upper part of the series is sandy ; northwards along this flank, sand-rock plays an increasing part in the succession, but the basal ferruginous conglomerate still forms steep hills in the Minbu-Pakokku borders (Kamedaung) and is but one of many others which succeed it.

Selenite, which is such a conspicuous feature in the Pegu beds, is not typical of the Irrawadian but may be present in small quantities through a short vertical distance above the Red Bed. Of the conglomerates the pebbles consist for the most part of milky quartz ; others are composed of sandstone quartzite, ochreous mudstone, schist, schist veined with quartz, dark shale and in some places silicified lava. A considerable quantity of coarse, almost pebbly sand is

[233] G. E. Pilgrim, Rec. 33, 158 (1906).
[234] Gen. Rep. Rec. 65, 96 (1931).
[235] Mem. 10, 250 (1873).

usually present in the interstices, and the cementing material is calcite and iron oxide in varying proportions. Along parts of the eastern margin of the Irrawadian main outcrop the conglomerates are described as white with kaolin. Some of the finer varieties of Irrawadian conglomerate show current-bedding.[236] The presence or absence of conglomerates depends as much upon geographical position as upon horizon. They are, for instance, enormously developed along the eastern flank of the Arakan Yoma, from the Axial, Negrais and Disang rocks of which chain they were no doubt derived. Along the eastern side of the main outcrop also they are strongly developed, and 600 feet of them are recorded north of Meiktila. Along the foot of the Arakan Yoma there is a tendency for the conglomerate to increase in coarseness from below upwards. The same tendency is seen as we approach the western flank of the synclinorium, but the coarser varieties are not confined to these marginal tracts, and pebbles and boulders 12 or 18 inches across are quite frequent in the more central areas such as the bank of the Irrawaddy at Yenangyaung.

The greater bulk of the Irrawadian, at any rate along the more central tracts, is made up of loose, friable, clean, light yellow sand-rocks, highly current-bedded, frequently iron-stained and often containing concretions of hard calcareous sandstone. This sand consists for the most part of water-worn sub-angular quartz grains, with a little intermixed felspar, and is a much purer deposit than the typical Pegu sandstone. Mica is frequently a constituent, especially in the higher beds. Most frequently the iron-staining coincides with the current-bedding planes. A great deal of ferruginous matter is present, mostly in the form of small concretions of limonite or hematite. A common type of such concretions, occurring in strings and layers in the sand-rock and reminding one of similar features in the English Red Crag, consists of an external crust of concentric layers of hematite or limonite, spheroidal, ellipsoidal or fantastically irregular in shape, enclosing a kernel, loose or otherwise, of yellow or red ochre, or of white clay; the external surface is roughened with adherent sand particles. The iron-coated clay pebbles described as constituting some of the ferruginous conglomerates are a form of these concretions. Manganese in the form of psilomelane sometimes takes the place of the iron-ore, and Theobald speaks of "irregular tabular masses of manganese-ore" in Toungoo.[237] There is every gradation between these strings of concretions and mere streaks of iron-stained sand. Under the Burmese rule iron was extensively manufactured from these concretions, especially in the neighbourhood of Mt. Popa in the Myingyan district; slag heaps and remains of furnaces testify to this almost extinct industry.[238] It is this sand-rock which forms the stems of the "capped pillars" already below.

The calcareous concretions are of two kinds, (i) small, root-like or sponge-like and (ii) spheroidal or ellipsoidal. The first, although

[236] Gen. Rep. Rec. 60, 84-85 (1927).
[237] Mem. 10, 267 (1873).
[238] E. H. Pascoe, Mem. 40, 33-34 (1912).

extremely characteristic, are of recent formation and are due to the deposition of calcareous matter around the roots of plants, the remains of which can sometimes be seen inside. In some places such tabular concretions have penetrated to depths of over 20 feet.[239] The larger, more or less spheroidal concretions are a more important feature and average from 2 to 3 feet across. Although much harder than the first variety, they are of secondary origin, and the laminae of deposition can generally be traced across the boulders which are often fissile along these planes; in other cases they fracture spheroidally like onions. These concretions are not rare in the Pegu beds, but are more typical of the Irrawadian which contains greater thicknesses of the soft porous sand necessary for their production. When such conditions occur, they are seen in vast quantities, and give rise to scenery of a remarkably grotesque nature.

Flat slabs of calcareous sandstone are not uncommon in the Irrawadian, but do not reach any great thickness nor extend to any great distance. Alternating layers of sand and clay, similar to those so typical of Pegu rocks, are observable, especially near the base of the series, but clay is not plentiful and occurs most commonly in pockets. Balls of clay, up to one or two feet in diameter, are in places numerous in the sand-rock. Both these and the clay pockets appear to represent portions of cliffs fallen into Irrawadian waters. In the Pegu district Clegg describes an exposure showing thin layers of hardened clay broken into wisps, evidently representing sun-cracked layers of mud lying upon and covered by sands.[240]

Contrast to the Pegu.—Although the boundary is not always easy to define, the contrast in general character between the Irrawadian and Pegu is marked and unmistakable. The newer series or facies, with its coarser and much less coherent sediments, is readily distinguishable from the more homogeneous and well-bedded rocks below, whose sequence is more argillaceous and whose silts show greater admixture and impurity. While the Pegus usually show dip and scarp structure, the incoherence of the Irrawadian has resulted in a characteristic type of scenery, which is that of a plain intricately dissected by branching tortuous, often deeply-cut watercourses; such a terrain is exactly similar to the "Bad Lands" of western Nebraska or to parts of California.[241] The Irrawadian country has a peculiarly clean and bright aspect and is linked in the minds of most visitors with the innate gaiety of its people. "Capped pillars" are common, and a similar phenomenon, especially noticeable in the more rainy Chindwin area, occurs in the form of bushes and small trees, sometimes with a collection of stones and boulders around their base, standing on conical mounds of sand. In contrast to the flora of the Pegu rocks, which are frequently covered with dense jungle, the sparsely scattered, stunted bushes and trees of the Irrawadian measure like living mile-posts of its aridity. This contrast is well

[239] Gen. Rep. Rec. 60, 83-84 (1927).
[240] Gen. Rep. Rec. 62, 117 (1929).
[241] E. H. Pascoe, Mem. 40, 7 (1912)

exemplified in Magwe, where the Government Reserve Forest Boundary, separating the rich teak forests of Sun and Sadon from the scanty scrub jungle of the surrounding country, coincides with astonishing closeness with the Pegu-Irrawadian contact.[242] The most important trees of the Irrawadian terrain include: the *in* (*Dipterocarpus tuberculatus*), the *ingyin* (*Pentacme suavis*), the *thaukkyan* (*Terminalia tomentosa*) and the *myinwa* (*Dendroclamus strictus*); the first two of these are practically absent from Pegu outcrops. Other trees characteristic of the Irrawadian are: the *than* Or Toddy Palm (*Palmyra Palm ; Borassus flabelliformis*) the *te* (*Diospyros birmanica*) and the *thitya* (*Shorea obtusa*).[243]

Relationship to the Pegu.—As would be expected, the relationship of the Irrawadian to the subjacent Pegus varies in different places. In some localities the hiatus between the two must have been of the briefest, and the one is seen dovetailing into the other. Examples of such gradual passage can be seen along the western slopes of the Pegu Yoma in Magwe,[244] and along the east side of the southern end of the same hills in the Pegu district.[245] In parts of Magwe, Meiktila and Shewbo Hamethin it is difficult to decide where the Pegu ends and the Irrawadian begins. In the Prome district the Akauktaung stage, which forms the top of the Pegu series in these parts, passes up without a break into beds of typical Irrawadian aspect.[246] Along the flanks of the Minbu anticline the boundary is also very vague. On the other hand, in the western parts of the Minbu district, a distinct unconformity, although not always visible, has been traced by Cotter and is accompanied by an appreciable variation in thickness of the Pegu beds below ;[247] nevertheless, along this western margin of the great synclinorium, the stratigraphical gap between the top of the Pegu and the base of the Irrawadian, when existant, is thought by the same observer to be quite small.[248] In the southern part of the Yenangyaung oilfield dome, the Irrawadian, dipping at about 9°, can be clearly seen resting upon the denuded edges of the Pegus which exhibit a dip twice as great.[249] In the Payagyigon southerly extension of the Gwegyo anticline in Myingyan, the transition from the blue shales of the Pegu to the red bed at the base of the current-bedded Irrawadian sandstones is very sharp, and marine fossils are found in the order series within 100 feet of the boundary ; in the Pegan anticline to the north the contact is also believed to be an unconformable one. The Pegu-Irrawadian unconformity is clearly seen in the case of some Pegu inliers west of the railway in Sagaing.[250] In other parts of Sagaing and in the adjoining tracts of the lower Chindwin district, where the Upper Tertiaries as a whole lie

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[242] Gen. Rep. Rec. 60, 84 (1927).
[243] H. L. Chhibber, Trans. Min. Geol. Inst. Ind., 21, 340 (1927).
[244] Gen. Rep. Rec. 60, 83-84 (1927).
[245] Gen. Rep. Rec. 58, 51 (1925) ; Gen. Rep. Rec. 62, 116 (1929).
[246] M. Stuart, Rec. 41, 246 (1911).
[247] Mem. 72, 102-103 (1938).
[248] Mem. 72, 101 (1938).
[249] E. H. Pascoe, Mem. 40, 65, Pls. 10, 11 and 12 (1912).
[250] Gen. Rep. Rec. 60, 84-85 (1927).

unconformably upon the crystallines, although the older Pegu series passes up into the younger, the latter overlaps the former. At the southern end of the Myaing anticline in Pakokku the current-bedded Irrawadian sandstones rest upon marine beds belonging to the Yaw stage of the Eocene, the transition from one to the other being abrupt. There is a complete overlap here of the Pegu by the Irrawadian, but to the northwest of Myaing, between the Yaws and the Irrawadian, there come in Pegu beds which, being of a very shallow-water facies, give the appearance of being of a transitional character.[251] The erosion accompanying the unconformity may in some places have been caused or magnified by volcanic disturbance in addition to tectonic movement. This appears to be the case in parts of the Lower Chindwin as it is in portions of the Pakokku district. Near the Shinmadaung volcano of the latter area there is a marked unconformity between the Pegu and Irrawadian, accompanied by the usual highly ferruginous deposits; when traced northwards, however, both unconformity and ferruginous beds die out and the boundary is difficult to trace, the one series mingling with the other by imperceptible gradations.[252] In the Lower Chindwin district the Irrawadian in places rests unconformably upon the Pondaung stage of the Eocene where not faulted against it.[253]

Basal Beds.—Where the Pegu-Irrawadian contact is unconformity, the lowest bed of the younger series is nearly always of a lateritic nature and evidently the remains of an old soil of surface deposit. In some cases its presence is the only evidence of an unconformable relationship. It varies in texture and composition but its chief feature is its deep red colour resulting from the large proportion of iron oxide present. In its commonest form this "Red Bed", as it has been called consists of a brick-red clayey sand, soft, friable and easily removed by denuding agents; it is commonly seen below the tops of cliff sections capped by harder beds. It is unstratified, and resembles to a striking degree the Plateau Red Earth of Pleistocene age which covers so large a portion of the lower plateaux of Burma. Along the western margin of the Yenangyaung oilfield the younger deposit rests immediately upon the Red Bed for some distance and, although the two are readily distinguishable from each other by a slight accidental difference in tint, the inference is inevitable that they must have had a very similar, if not identical origin.[254] Another similarity, observable in the Sadaing Myauk Chaung, Yenangyaung, is the local irregularity of the unconformable contact between the Red Bed and the Pegu, and the still more irregular, almost serrated junction between the Plateau Red Earth and Irrawadian in some places. As an alluvium or soil the Red Bed in many places must have been removed by denudation before the deposition of the first fluviatile sediments. The Red Bed is some-

[251] G. de P. Cotter, Mem. 72, 101 (1938).
[252] Gen. Rep. Rec. 60, 86-87 (1927).
[253] Gen. Rep. Rec. 61, 110 (1928).
[254] E. H. Pascoe Mem. 40, 30 (1912)

times mottled with yellow. Elsewhere the clay constituent is individualised in the form of clay pebbles coated with a hard layer of iron oxide, and lying in either a loose, impure, ferruginous sand, or a hard matrix of similar composition; sometimes the matrix is harder than the pebbles of clay which consequently weather out, leaving a curious, cellular rock. Lastly it may contain small quartz pebbles in addition to the clay, and may form a compact ferruginous conglomerate.

In the Singu anticline the Red Bed or basal conglomerate is from 2 to 3 feet in thickness, sometimes increasing to 6 feet. In the Yenangyaung dome it averages 5 or 6 feet, but a few additional ferruginous conglomerates are interstratified among the basal beds of sand-rock in some sections, a few feet higher up. The thickness of the basal conglomerate in west central Minbu is up to 20 feet, but a little higher there occurs a great thickness of conglomerate beds. In the Yaw river section and other parts of Minbu where it often contains white quartz pebbles, it may swell to 100 feet.

The horizon of the Red Bed is sometimes confused by the development, below and more especially above, of other similar beds; such repetitions, which are by no means unusual, make it difficult to decide in some cases which bed is to be taken as the lower limit of the Irrawadian. In the Singu anticline Sethu Rama Rau records many ferruginous sandy layers, ranging from brick-red sandstone to lateritic conglomerate, intercalated in the 40 or 50 feet of the bright White Sand which forms the top of the Pegu succession.[255] Here, however, the beds above the White Sand contain vertebrate remains and fresh-water shells, the boundary Red Bed has been traced without difficulty and with scarcely a break along the western flank of the long Singu-Yanangyat fold; it is especially well developed round the northern nose of the pitching anticline, but is missing along nearly the whole of the eastern flank. In the Gwegyo-Payagyigon fold the basal Red Bed is 3 or 4 feet thick and grades into a conglomerate. Where there is a gradual passage from the Pegu to the Irrawadian, the Red Bed may be either entirely absent, or represented by numerous thin ferruginous layers at several horizons; no distinct red or conglomeratic band, for instance, can be recognised on the west side of the Pegu Yoma at its southern extremity.[256] In the northern part of the western half of Pakokku the boundary Red Bed disappears and the Upper Pegus traced from the south are described as exactly like the Lower Irrawadian traced from the north; northwards from this point another red bed lower down in the sequence becomes exceptionally thick and prominent and, although accompanied by several thinner red beds both above and below, marks the vertical change from the Pegu facies to the Irrawadian facies In this way there appears to be a vertical echelonnement downwards of the Pegu-Irrawadian boundary, using the term facietally, from south to north. One might well except repetitions of this to lower

[255] Rec. 53, 329 (1921).
[256] Gen. Rep. Rec. 58, 46 (1925).

levels further in the same direction. There is thus some reason to believe that neither the Red Bed nor the unconformity below it is of the same age throughout Burma, but that both are older in the north than they are in the south.[257]

In Henzada the marginal deposits of the Irrawadian, in the form of lateritic gravel of loose conglomerate, lie upon a very gently sloping bank of older rocks; in a westerly direction this gravel is described by Stuart as becoming reduced to a thin deposit cut through by streams which expose the older rocks beneath.[258]

Vertebrate remains.—With regard to fossils, there is no reason why vertebrate remains should not be found at any horizon, whereever conglomerates happen to be present, but such occurrences have proved to be irregular, capricious and local. Vertebrate fragments, sometimes rounded or worn by erosion[259] are occasionally found in the conglomeratic variety of the Red Bed and are in some places plentiful in the strata immediately above. From this horizon the majority of the specimens so far collected from the Irrawadian seem to have been derived. From the Yenangyaung and Singu oilfields the following have been identified.[260]

CHELONIA.

Chelonian plates, including *Trionyx* (very common).

REPTILIA.

Crocodilus or *Garialis* sp.

PROBOSCIDEA.

Stegodon elephantoides (Clift) (Pilgrim's *Stegodon clift*),[261]
Stegolophodon latidens (Clift), (Middle Siwalik form),
Dinotherium sp.

PERISSODACTYLA.

Aceratherium lydekkeri Pilg. (Middle Siwalik form),
Hipparion punjabiense (Lyd.) (Middle Siwalik form; considered by some to be identical with *H. antelopinum*),[262]
Rhinoceros teeth and jaw.

ARTIODACTYLA.

Mehycopotamus dissimilis Falc. & Cautl. (Middle and Upper Siwalik),
Hippopotamus (Hexaprotodon) irravaticus Falc & Cautl.,
Tetraconodon minor Pilg. (from both Singu and Yenangyaung; Middle Siwalik form),
Hydaspitherium birmanicum Pilg. (from Singu),
Vishnutherium iravaticum Lyd.,
Pachyportax latidens Lyd., var. *dhokpathanensis* Pilg (species a Middle Siwalik form), [263]
Cervus sp. (jaw; from Singu).

[257] Gen. Rep. Rec. 45, 126 (1915).
[258] Rec. 41, 251 (1911).
[259] F. Noetling, Rec. 30, 242-249 (1897).
[260] G. E. Grimes, Mem. 28, pt. 1, 46, 63 (1898); L. D. Stamp, Geol. Mag. 59, 497-498 (1922).
[261] Rec. 43, 284 (1913); Bull, Amer, Mus. Nat. Hist., 74, 409 (1938).
[262] Bull Amer. Mus. Nat. Hist., Vol. 74, 401 (1938); also Trans. Amer. Phil. Soc. N. S. 26, 129-132 (1935).
[263] Bull Amer. Mus. Nat. Hist. 72, 766 (1937).

According to Noetling and Stamp, *Hippopotamus irravaticus, Stegodon elephantoides* and *Stegolophodon latidens* occur some 4,000 feet above the Red Bed at Yenangyaung and have not been found in the basal zone which yielded *Aceratherium lydekkeri* and *Hipparion punjabiense*. Although *Hippopotamus* at any rate, if not the two proboscidean species named above, is occasionally found in the Dhok Pathan stage of the Punjab, yet the abundance of the first named genus in the Tatrot stage renders it probable that the upper fossil zone at Yenangyaung is the equivalent of the Tatrot in north-west India. In conformity with this suggestion the occurrence in lower bed of *Aceratherium lydekkeri, Pachyportax latidens* var. *dhokpathanensis, Tetraconodon minor, Hydaspitherium birmanicum* and probably *Vishnutherium birmanicum* clearly indicates a Dhok Pathan age, equated by Pilgrim with the Pontian of Europe.[264]

Dhok Pathan is also probably the age of most of the fossils collected by Crawford on the left bank of the Irrawaddy near " Wetmasut "[265] about halfway between Ava and Prome described by Clift in 1828. These include:

ARTIODACTYLA.

Proleptobos birmanicus Pilg.,
Bos sp.,
Sus sp.,
Hippopotamus sp.

PERISSODACTYLA.

Tapirus sp.,
Aceratherium lydekkeri Pilg.,

PROBOSCIDEA.

Stegodon elephantoides (Clift),
Stegolophodon latidens (Clift).

The *Bos*, according to Pilgrim (private communication), is an advanced form and indicates an age no older than the Pinjor of India. *Proleptobos* is an ancestral form of the Pliocene *Leptobos*.[266] Teeth of *Equus* found at various places along the Irrawaddy river below Yenangyaung afford a similar indication of Upper Siwalik age.

From Chaingzauk in Pakokku an assemblage, said to occur some way above the base of the Irrawadian series and consisting chiefly of teeth, probably belongs to the Dhok Pathan stage since, in addition to an enormous carapace of *Colossochelys atlas*,[267] *Stegodon elephantoides, Rhinocers* cf. *sivalensis, Hexaprotodon* cf. *irravaticus, Proamphibos* cf. *lachrymans,* and a large and probably hippotragine antelope, it also contains *Sivachoerus prior, Pachyportax latidens,* var. *dhokpathanensis,* and *Tragoportax* cf. *islami*.[268] The Red Bed west of Yenangyat is said to have yielded various fossils including verte-

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[264] Guy E. Pilgrim, Rec. 40, 196 (1910).
[265] Wetmasok—probably the village of that name in Magwe, half-way between Yenangyaung and Ondwe.
[266] Rec. 43, 304 (1913).
[267] G. de P. Cotter, Mem. 72, 106 (1938).
[268] Gen. Rep. Rec. 45, 126 (1915) ; Gen. Rep. Rec. 54, 115 (1922).

brates;[269] a calcareous bed at Tabingyaung, west of Yenangyat and traceable for a considerable distance, has also yielded numerous vertebrate remains, perhaps of Upper Siwalik age.[270]

Barnum Brown has collected *Stegodon insignis*, var. *birmanicus* Osb. from Mingun, opposite Mandalay,[271] and *Hypselephas hysudricus* Falc. & Cautl., from the so-called Upper Irrawadian beds[272] near Thanudaw[273] as well as from the Upper Irrawadian along the Chindwin river about three hundreds miles north of Mandalay.

From the vicinity of Mt. Popa in Myingyan come stegolophodont or stegodont proboscids allied to *Stegolophodon latidens* and *Stegodon stegodontoides*. This horizon appears to form the local base of the Irrawadian in the Yenangyaung oil field.[274]

Besides the occurrences mentioned, there are isolated records of the species named above from various localities in Burma: *Stegodon* sp. from south of Kabaing, Lower Chindwin; fragmentary bones and teeth of *Rhinoceros, Merycopotamus* (?) and other mammals, a chelonian skull and costal plates, and crocodile scutes, from near Manktet, Shwebo district; *Emyda palaeindica* Lyd. from Pakokku and the vicinity of Yenangyaung; fragments of *Rhinoceros* and *Stegodon* teeth, from near Tingyokpin in Pakokku;[275] *Gharialis gangeticus* Gmel. (a form living in the present Ganges and Jumna), *C. leptodus* Falc. & Cautl., *Testudo* sp., *Hipparion theobaldi* (Lyd.), and *Tapirus* (?) sp., all from "Burma".

It seems practically certain that the Irrawadian series south of Mandalay comprises horizons extending from the Dhok Pathan up to the Pinjor stages of northwest India, but no stratigraphical limits can yet be assigned to them. On the other hand, some distance further north, at Taungbyin-nge in the Lower Chindwin district, it is not surprising to find that the fauna of the basal Irrawadian is two stages older than it is at Yenangyaung and has been referred to some part of the Chinji stage,[276] or at latest Nagri (Sarmatian). In this interesting collection, made by A. E. Day, the Middle Siwalik forms found at Yenangyaung are all absent, and there is present an altogether new proboscid fauna of which not a single species appears to be definitely assignable to any Indian form. The following preliminary determinations have been made:

PROBOSCIDEA.

Trilophodon cf. *falconeri* Lyd. (species found in Sind.),
Several teeth of a *Trilophodon* allied to but more advanced than *Tr. angustidens*, var. *palaeindicus*,
Trilophodon aff. *pandionis*.
A form reminiscent of *Hemimastodon crepusculi*,

[269] Gen. Rep. Rec. 41, 74 (1911).
[270] Gen. Rep. Rec 41, (1911).
[271] Amer. Mus. Nov. 393, 15, 16 (1929).
[272] ? Plateau Gravel.
[273] Colbert, Bull. Amer. Mus. Nat. Hist., 74, 416 (1938)
[274] Gen. Rep. Rec. 60, 19 (1927).
[275] G. de P. Cotter, Mem. 72, 106 (1938).
[276] Gen. Rep. Rec. 60, 19 (1927).

The youngest looking proboscid in the collection may be an ancestral form of *Prostegodon latidens* Clift.

ARTIODACTYLA.

Listriodon pentapotamiae,

Jaw of a large pig, probably a small species of *Sivachoerus*.

According to Pilgrim,[277] the general character of the mammal fauna of the Irrawadian period indicates that Burma was to a large extent isolated from India and formed a separate zoological province, especially during the Miocene. This is shown markedly by the Proboscidea, no single species of which is identical with any found in India, while in the case of the Taungbyin-nge fauna of Chinji age probably even generic differences exist; the proboscids of the pre-Pleistocene deposits of Burma, in fact, show far closer affinities with those of Borneo and Java than they do with those of India. In the case of the Suidae, Anthracotheriidae, Bovidae and Perissodactyla, a closer parallel to India seems to exist, but even here *Proleptobos, Sivaportax* and *Tapirus* are so far unknown in India and the general, *Tetraconodon, Hydaspitherium, Vishnutherium, Hippopotamus,* and *Tragoportax* are represented by species different from the Indian ones. The existence of long marine gulfs would account for the isolation of the Burmese mammals and their parallel development to that of Indian forms, when once we have explained how they reached Burma originally. Since most of the Burmese forms named are supposed to have originated either in India or in the countries to the west thereof, it seems most likely, in Pilgrim's opinion, that they entered Burma from India or Persia by way of central Asia and China, but the palaeontology of the countries named, including Burma itself, is still so fragmentary, especially in the Miocene epochs, that questions of migration are obscure.

Invertebrate Fauna.—So far as invertebrates are concerned, from basal Irrawadian in northwest Thayetmyo have been collected two unionids and a large melaniid, the latter in great abundance, and all three closely related to living species, these are: *Indonaia glyptica* Vred. (close to the modern *I. crispata* of Burma, Siam and Cambodia). *Pareyssia latouchei* Vred. (very close to *P. tavoyensis*,[278] and a variety of the living *Acrostoma variabile* (Benson), one of the commonest and most characteristic species of fresh-water gastropods in Burma. The giant fresh-water *Batissa sethuramae* Vred. has been found in the basal Irrawadian bed of Yenangyat and at the same horizon in the Minbu anticline. From the same bed in the Yenangyaung field some specimens of *B. crawfurdi* Noetl. (including "*B. petrolei*"), crowded together, in good preservation and mostly with valves united,[279] as well as the larger *B. kodaungensis* Noetl. *Taia (Rivalarioides) spinifera* Annand have been collected from this horizon in the Yenangyat area.[280] From the basal mbed in Yabethin

[277] Private Communication.
[278] Rec. 51, 374 (1920).
[279] E. H. Pasoce, Mem. 40, 63 (1912).
[280] Rec. 50, 236 (1919).

comes a *Batissa* having affinities with the living *B. similis* Prime. Near Lewa in the same district have been found abundant specimens of a large *Batissa,* mostly with valves united, closely related to but much larger than *B. inflata* Prime ; with it were specimens of a small *Corbicula* and casts of a *Unio.*[281] Casts of *Batissae* are reported from various places in the Lower Chindwin and Shwebo districts.[282]

Vegetable remains.—The extraordinary profusion of the now classical constituent of the Irrawadian sandstones and conglomerates, fossil wood, has been noted by every traveller who has visited Upper Burma, including Symes in 1795 at Yenangyaung, Crawfurd at Prome in 1827, and Captain Yule who adduces its existence as an explanation of the stories current in his time of the wooden posts of monasteries becoming petrified.[283] In the neighbourhood of Yenangyat village and in parts of Myingyan, some of the fossil wood is calcareous, but the vast majority of the trunks are siliceous. By far the greater part of the remains is dicotyledonous, but monocotyledonous wood is not very rare in Upper Burma. The Burmans claim that it represents two living species, the *ingyin* tree, and the *thity.* The former is identified by Brandis with *Pentacme suavis* A. DC. (Syn. *Pentacme siamensis* Kurz or *Chorea siamensis* Miq.) referred to by Theobald as *Hopea suava* ;[284] the latter, according to Theobald is *Shorea obtusa,* or, if we accept the authority of the Upper Burma Gazetter,[285] the *Gordonia floribunda.* Miss Ruth Holden's examination of a calcified specimen of fossil wood from the Irrawadian of Gwebindon in Sagaing has shown that this resemblance noted by Burmese village folk is not so illusory as Theobald imagined ; she assigns the species to the Dipterocarpaceæ under the name of *Dipterocarpoxylon burmense* and notes that among living forms *Shorea* is nearest to her specimen. From the Tertiary of Sumatra a very similar fossil wood has been named *Dipterocarpus verbeckianus* and *D. antiquus,* Heer.[286] Remains of palms, showing clearly the cordiform wascular bundles and their obliquity to the stem axis when about to enter a leaf, appear to be more plentiful near the Pegu-Irrawadian boundary ; clumps of monocotyledonous roots exactly similar to the intertwining adventitious roots of palms are sometimes found. Much of the silicified dicotyledonous wood is beautifully preserved ; in some crumbling specimens individual xylem vessels can be separated with a pocket-knife. When fractured it usually breaks along the grain, often along an " annular ring ". Noetling claims to have found pieces riddled by the borings of xylophagous molluscs, but no reliable instance of such parasitism is recorded in the Irrawadian and there can be no doubt that Noetling's specimens were derived from the marine Pegu and not from the Irrawadian in the sense of the term adopted in this

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[281] Gen. Rep. Rec. 58, 46 (1925).
[282] Gen. Rep. Rec. 66, 104 (1932).
[283] Symes ; Embassy to the kingdom of Ava in 1795 p. 262 ; Crawfurd. Embassy to the court of Ava in 1827, p. 33 ; Yule. Mission to the court of Ava, p. 12.
[284] Rec. 47, 267 (1916).
[285] J. G. Scott. and J. P. Hardiman, Glossary, 7.
[286] Gesellsch. f. d. Naturwissensch. Zurich (1883).

work.[287] All wood found floating on the sea or in the tidal creeks of India at the present day, and even the dead trunks and branches in places flooded by the tide, are riddled by boring Teredinidae or Pholadidae, and the absence of such a phenomenon in the fossil wood of the Irrawadian proves that it could not have been immersed for any length of time in salt water. The sharks' teeth discovered occasionally among the Irrawadian sediments must either have belonged to species which inhabited rivers, as some do today, or have been derived from the Pegu beds below. Water-worn fragments of fossil wood are not infrequent constituents of the basal Irrawadian conglomerate.

Buckland mentions stems of fossil wood from 15 to 20 feet long and 5 feet in circumference, observed by Crawfurd and Wallich a little south of Yenangyaung.[288] T. Oldham found one log 3 feet 4 inches in diameter,[289] and Theobald came across broken trunks from 40 to 50 feet in length.[290] One-and-a-half feet in diameter may be taken as an average size, but branches of all diameters are to be found. It may occur in any sandy horizon of the formation but is especially abundant in the higher portion thereof, and the surface of any such deposit is commonly strewn with these fractured logs which have weathered out of their soft habitat. The wood, especially the larger masses thereof, show signs of attrition and decay, as if the stems had been transported to a distance and rolled before being silicified. It is impossible for the stems to have been silicified to any extent before they were embedded in the sediments.

Much has been written concerning the formation of such silicified wood, which has obviously exerted an influence in localising a deposition of silica. It is to be found in several of the islands of the East Indian Archipelago and in the Libyan Desert. In the last mentioned country its formation is accounted for by H. G. Lyons,[291] by the action of water containing sodium carbonate upon felspar, producing sodium silicate which, acted upon by the acids in the decomposing wood, gives rise to sodium salts of these acids and colloidal silica. Such an explanation may well apply in the case of the Burma occurrences. Most of the water that rises from any depth in Burma is salt, alkaline and often highly impregnated with sodium carbonate. There must have been an abundant supply of the latter salt in Irrawadian times, as well as a plentiful source of felspar in the volcanic products emitted at various localities throughout the period and especially towards its end. The soluble silicates would be distributed by the rivers. Experiments have shown that the quantity of silica brought down in solution by rivers may be great; in the Nile at Cairo, for example, the amount is 43.39 grammes per cu. metre, in the Rhine at Strasbourg it is 488 grammes.[292] The silicified logs

[287] W. Theobald, Rec. 28, 151 (1895).
[288] Crawfurd. Embassy to the court of Ava in 1827, Append. 13, p. 82.
[289] Yule. Mission to the court of Ava, Append. p. 312.
[290] Mem. 10, 252 (1873).
[291] Q. J. G. S., Vol. 50, 531 (1894).
[292] Justus Roth Chemische Geologie, 1, p. 462.

are never found upright but always prone and parallel to the bedding planes with mere stumps of branches. They have the appearance of drift wood which, after being denuded of most of its branches by decomposition and rough treatment in swirling waters, has sunk when water-logged and become rapidly covered by sand-banks. One has only to sail up the Irrawaddy today during the rainy season to see the way in which such vast quantities of timber may have been carried off by the river's ancestor. Trunks and branches in all stages of dismemberment and saturation are met floating down, while every now and then the edge of the sandy cliff gives way, precipitating trees and bushes into the water.[293]

Fossil wood is more plentiful in some places than in others. In parts of Sagaing and the Lower Chindwin, for instance, trunks of it are abundant except in the lower horizons of the series.[294] Long trunks of it cover the ground in Shwebo, some of them suggestive of palm trees.[295] In the Ngape area of Minbu, on the other hand, it is less plentiful than it is on the oilfields;[296] around Yamethin and Pyinmana it is scarce. Silicified wood is used by the Burmese as a flint for obtaining fire, and also for posts. When well silicified it emits a bell-like sound on being struck and is used for gongs in Burmese Monasteries. In Shwebo it is used as ballast on the railway, as a holy stone and as road-metal.[297]

Fossil plant impressions on shales, some of them resembling *Phyllites kamrupensis* Sew. from the Coal measures of Assam, have been found near Taungu in the district of Shwebo.[298]

Thickness.—No reliable estimate of the maximum thickness of Irrawadian sediments surviving in Burma has been made. To the west of Yenangyat approximately 8,500 feet are exposed.[299] Noetling's estimate of 20,000 feet between the Pegu exposure of Singu and Salemyo[300] is far in excess of the truth, for the thickness here can scarcely be more than 4,000 feet. Between the oilfield of Yenangyaung and the river Irrawaddy it is between 4,000 and 4,500 feet, while east of the field, between it and the next Pegu inlier of Wetchok-Yedwet, some 5,000 feet are exposed.

The Upper Boundary.—Many of the statements made regarding the lower limit of the Irrawadian apply also to the upper. In some places there appears to be a gradual passage into Pleistocene or Recent deposits, while elsewhere there is a marked discordancy characterised by a red bed, the Plateau Red Earth or its equivalent, the Plateau Gravel. In parts of Shwebo the Irrawadian-Alluvium boundary is never clearly defined, the one passing imperceptibly into the other.[301]

[293] E. H. Pascoe, Mem. 40, 41-42 (1912).
[294] Rec. 60, 85 (1827).
[295] Gen. Rep. Rec. 67, 48 (1933).
[296] G. de P. Cotter, Rec. 41, 221 (1911).
[297] Gen. Rep. Rec. 65, 35 (1931).
[298] Gen. Rep. Rec. 65, 23 (1931).
[299] Gen. Rep. Rec. 41, 74 (1911).
[300] Rec. 28, 77 (1895).
[301] Gen. Rep. Rec. 65, 90 (1931); Gen. Rep. 67, 48 (1933)

In Thayetmyo some of the loose Irrawadian conglomerates have been taken for Plateau Gravel.[302] In the Pegu district the Irrawadian is described as stretching eastwards and southwards to the plains where it disappears beneath the alluvium of the delta, but both Clegg and Leicester suggest that the Lower Older Alluvium of Rangoon, with its lateritised surface, may be no more than a southerly representative of the latest Irrawadian.[303] In Magwe the Irrawadian beds are said to pass imperceptibly into the alluvium of the Taungdwingyi plain.[304] On the other hand, in southern Minbu the gravels and soft conglomerates of the Irrawadian can be generally distinguished from the Plateau Gravel by their dip,[305] and the same applies in Henzada where the Tertiary lateritic gravel has been involved in the folding and faulting. *Kankar* is apt to collect on the surface of Irrawadian rocks, especially near their boundary with the alluvium.[306]

The bulk of the Irrawadian is Pliocene, but its lower portion ranges down into the Sarmatian, or even earlier if the Taungbyin-nge beds are of Chinji (Tortonian) age. The lowest Irrawadian beds at Yenangyaung correspond to the Middle Siwaliks of northwest India, the Middle Manchhars of Sind and the Talar stage of the Makran.[307] The Upper Irrawadian may be correlated with the Gwadar stage of Makran, the Upper Manchhars of Sind, the Upper Siwaliks of northwest India, and the Sonde series of Java, shading up into the Pleistocene. Marine conditions seem to have persisted for a somewhat longer time in the Burmese gulf than they did in the gulf of west and northwest India, for the Lower Manchhars are represented by part at least of the marine Akauktaungs (Tji Lanang beds of Java; Vindobonian).

Northern Exposures.—The Irrawadian is recorded at Wuntho in Katha, and an outcrop has been recognised and mapped to the west of Homalin along the western side of the Upper Chindwin. Between these two localities and partly concealed by the alluvial deposits of the Chindwin, the beds form a broad synclinorium, the westerly limb dipping off the complex of so-called Axial beds in Manipur State, the eastern in the Wuntho area dipping westwards off the igneous massif of the Maingthong Hill Tracts.[308] This synclinorial belt has been corrugated into a number of minor folds similar to those known to exist in the Lower Chindwin area further south. North and northeast of the outcrop in the Upper Chindwin district there is a wide gap of unexplored country separating it from the Tertiary occurrences of the Jade Mines area in northwest Myitkyina and from those of the Hukawng valley.

From the farthest corner of Assam, across the country of the Singphos Murray Stuart has traced the Tipam series into the

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[302] Gen. Rep. Rec. 58, 45 (1925).
[303] Gen. Rep. Rec. 62, 116 (1929).
[304] Gen. Rep. Rec. 60, 83 (1927).
[305] G. de P. Cotter, Rec. 41, 221 (1911).
[306] Gen. Rep. Rec. 65, 36 (1931).
[307] G. de P Cotter, Rec. 54, 115 (1922).
[308] H. S. Bion, Rec. 43, 243 (1913).

Hukawng valley. Had he marched up from Lower Burma instead of from Upper Assam, there is not the slightest doubt that the Hukawng valley beds would have been classified as Irrawadian. The Hukawng valley, tributary to that of the Chindwin, consists of a broad alluvial tract in the midst of which crops out the small inlier of the Amber Mines consisting of syenite-gneiss and Tertiaries. The latter are found on the eastern flank of the Amber Mines hills, and comprise the Amber-bearing beds, which have been already considered (p. 1611), overlain by reddish grits or sandstones and reddish conglomerates, dipping eastwards at a low angle and forming the local base of the Tipam or Irrawadian series, whichever we like to call it.[309]

The Hukawng valley is situated on a broad flat basin of Tipam or Irrawadian sandstones covered by a broad central sheet of alluvium. On the south side of the latter the Tertiary beds have been traced from Tainpu Taung, where they have a gentle northerly dip, southwards to the vicinity of Ka-maing. On the north side of the alluvial tract the Tipams form a broad belt, the dip steepening to 45° in the Taron gorge, the north bank of which is formed of the dip-slope and the south bank the scarp face; this section is part of a mountain range of Tipam rocks of slightly harder character than usual. The basal beds of this belt are seen further north in the Gedu river section where the dip sinks to about 25° in a S. S. E. direction, and are conglomeratic, lying unconformably upon the slaty sandstones and shales of the Disangs; in these conglomerates are pebbles of the Disang rocks and of serpentine. North of the Gedu the E. N. E.-W. S. W. belt of the Disangs, some 20 miles across, is traversed by the Loglai, and is succeeded unconformably by another belt of Tipams, in the Singpho country, stretching northwards, to the Dihing in Assam and southwestwards to the Patkoi range, across which they form a broad syncline whose axis coincides approximately with the crest of the range.[310]

The eastern boundary of these Tipams lies along the western side of the Mali Kha and has been traced by Stuart for nearly 80 miles from latitude 26° N. to within a few miles of Langtao. Resting unconformably upon ancient metamorphic rocks and dipping gently W. N. W., *i.e.*, towards the Kumon range, the Tipam beds form one long ridge after another. Along the Putao road, which follows more or less the boundary with the schists, the sandstones are conglomeratic at their base, with pebbles of the rocks upon which they are superposed, especially north of latitude 26° 30′ where the basal beds are composed of thick coarse conglomerates with pebbles of the syenite-gneiss which intrudes the underlying metamorphics of the neighbourhood; for some distance above this basal conglomerate the sandstones are full of kaolin derived from the decomposing felspar in the subjacent gneiss. The sandstones, yellowish and whitish in colour, are frequently current-bedded and are interbedded with conglomerate. Thin bands of blue clay are rarely found, and have

[309] Gen. Rep. Rec. 65, 79 (1931).
[310] M. Stuart, Rec. 54, 402 (1922).

yielded leaf impressions, sometimes in great quantity; similar impressions are also seen on some of the sandstones.[311]

The highest beds of the series are exposed about midway between the Amber Mines and the Kumon range, in the Tanai Hka, one of the uppermost feeders of the Chindwin river, east of the Hukawng valley. These horizons are made up of boulder conglomerate consisting mostly of disintegrated boulders of quartz, mica-schist, graphite-schist, and other metamorphic types, of varying size, embedded in reddish or yellowish soil. Intercalations of sand occur in the conglomerate and are sometimes washed for gold. There can be little doubt that this sequence is the equivalent of the Dihing Conglomerate of Assam.[312]

The Jade Mines area of Myitkyina.—Some Upper Tertiary rocks in northwest Myitkyina have yielded heavy mineral residues similar to those found in the Tipams of Assam and may be approximately of the same age. They contain fossil wood and have been called by Chhibber the Namting beds, occurring between Namting and Lonkin a few miles W. N. W. of Kamaing, as well as in the low hills near Nanyaseik and in the Tarong Hka near Tarongyang.[313] These rocks, which in places are almost vertical and probably attain a considerable thickness, consist of sandstones, shales and conglomerates, with bands of finely jointed carbonaceous limestone and some coal and lignite.[314] The sandstones, which are of various colours, coarse to medium and sometimes pebbly in texture, contain many minerals; the most predominant of these are quartz and felspar, but grains of epidote, glauconite, chlorite and serpentine are common, some sections showing also muscovite, biotite, hematite, chromite, calcite, small grains of graphite and graphite-schist, and occasionally grains of jadeite, all occurring in a siliceous matrix. The majority of the sandstones are argillaceous but some are calcareous. The shales are generally rendered grey by carbonaceous matter, and contain a considerable amount of calcite; those from Hwekha, a few miles southwest of Namting, contain small Globigerinidæ. The conglomerate boulders include some of jadeite; near Hwekha they comprise several types of rocks including antigorite, peridotite, amphibolite, hornblende-graphite-mica schist and quartz-schist. Organic remains consist of small trunks of dicotyledonous and palm wood, the inner portion frequently carbonised and the outer silicified and impressions of leaves identified as *Tetranthera hwekonsis* Schuster, a close relative to the Bay tree, *Laurus*.[315] The Tertiary strata show considerable faulting and have been baked and hardened by intrusions of granodiorite, soda-porphyry and quartz veins. At the confluence of the Dabbum with the Chinkichu Hka the Tertiaries have been intruded by gabbro, in places on an intimate scale. These eruptions are thought to have been subaqueous in character and contemporaneous

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[311] M. Stuart, Rec. 50, 246 (1919).
[312] Gen. Rep. Rec. 65, 79 (1931).
[313] Gen. Rep. Rec. 66, 88 (1932).
[314] Gen. Rep. Rec. 62, 109-110 (1929).
[315] A. W. G. Bleeck, Rec. 36, 257 (1907).

with the deposition of the Tertiary sediments; rocks of a similar type and age are found in the Lower Chindwin district and on Mount Popa, and are described on page 1851.

The sediments just described are succeeded by the Uru Boulder Conglomerate, which may be tentatively correlated with the Dihing stage of the Tipams.[316] This is mainly a conglomerate formation made up of boulders deposited by a larger precursor of the Uru river and by torrents from the hills to the west.[317] The boulders of the conglomerate are water-worn and of all sizes from a few inches to several feet across, embedded in red earth or occasionally sand-rock. Since they belong to the youngest formation of the neighbourhood, they include representatives of all older rocks—altered peridotites, all varieties of serpentine (massive, antigorite, chrysotile, marmolite, etc.), rhyolite, siliceous breccia and colourless, pink or smoky quartz crystalline schists such as mica-schist, quartz-schist, glaucophane-schist and anthophyllite-schist, less commonly grano-diorite, diorite and epidiorite, occasionally and in smaller dimensions, chromite, hematite, limonite and jadeite. Underlying the Boulder Conglomerate there appears to be a sand-rock containing boulders, while lenticles of sand-rock occur in the conglomerates themselves; the heavy residues from this sand-rock, according to P. Evans, are distinct from those of the Namting beds and those of the earlier Khuma (Barail) beds, and are characterised by the absence of tourmaline, garnet, zircon and rutile.[318] In places a low dip can be seen in the rocks but seldom exceeds 10°. Cliffs over 300 feet high composed entirely of this conglomerate are not uncommon, and the maximum thickness noted is about 1,000 feet. At Hwekha the conglomerates are exploited for the jadeite boulders they occasionally contain.

Tenasserim.—In Tavoy and Mergui Tertiary rocks having the general facies of the Irrawadian of Upper Burma or the Siwaliks of India appear in disconnected patches over a length of more than 220 miles along the present-day valleys of the more important rivers. In each valley these disconnected outcrops were probably at one time part of a continuous whole, deposited either in a broad river valley or in a lake. They are folded synclinally, the predominant dip varying between 20° and 40°, and are often disturbed by minor faults. They rest for the most part on the Mergui beds but in one section of the Upper Tenasserim basin on the granite.

In Tavoy there are two belts of these rocks, one corresponding with the valleys of the Ban and Kamaungthwe, and the other less closely with the upper part of the Great Tenasserim river. They represent, according to Brown & Heron, areas of depression along parallel axes, separated by a barrier some 20 miles wide.[319] The Upper Tenasserim deposits have been very little explored.

[316] Gen Rep. Rec. 66, 87-88 (1932).
[317] Gen. Rep. Rec. 63, 100 (1930).
[318] Gen. Rep. Rec. 66, 88 (1932).
[319] Mem. 44, 194 (1923).

In the Ban-Kamaungthwe basin, which is covered with bamboo jungle in contrast to the evergreen forest of the surrounding mountains, the rocks consist mainly of conglomerates and shales with some sandstones and in a few places thin impure limestones and lenticular bands of pyritiferous lignite about 6 inches thick. The deposits which are found in interrupted outcrops over a distance of 45 miles, become finer from below upwards. At the base is a conglomerate with pebbles of white vein quartz, Mergui quartzite and argillite, and granite, often in a ferruginous matrix while at the top are shales which are very finely laminated and flexible when damp. The sandstones are usually coarse, current-bedded and contain pebbly layers. The only organic remains are fragments of silicified or carbonised wood occurring in the shales and the conglomeratic sandstones.[320] One trunk of lignite is reported as about 10 feet long and a foot in diameter.

To beds of a similar character in a lower part of the Great Tenasserim valley, in the district of Mergui, P. N. Bose has given the name of the Tendau series.[321] These sediments crop out for about a mile or so on each side of the Great Tenasserim river throughout a length of some fifteen miles between Tendau and Kamapying, and were obviously laid down by a precursor of this river. Here and in other parts of Mergui the order of sequence is the reverse of what it is in Tavoy, the beds consisting of shales with workable coal seams below and conglomerates with interbedded sandstones above. The shales, which are greyish white to black in colour, are well exposed on the west side of the river but thin out to the east and finally seem to disappear. The pebbles of the conglomerate, some of them a foot in diameter, are sub-angular and consist mostly of argillite and slate derived from the more steeply inclined Mergui beds on which the Tertiary sediments unconformably lie; the matrix of the conglomerate also is clayey rather than sandy. In places, according to S. S. Rau, the Tertiaries overlie, also unconformably, the Moulmein Limestone. The sandstones interbedded with the conglomerates are soft, massive and current-bedded. Seams of coal occur from 6 to 17½ feet in thickness, varying rapidly in size and swelling in some cases to over 28 feet. The coal, which is found only on the west side of the river and has been worked, has a low ash but high sulphur percentage, like that of Assam. The estimated reserves are some 50 million tons, some of it of good quality though high in moisture. Some plant impressions, mostly dicotyledonous, and some fish remains are reported. The Tendau beds lie in a syncline the axis of which varies in direction from N. E.-S. W. to N. N. W.-S. S. E., the dip averaging 30°.

Similar rocks have been found in the Theinkun, Lenya and Pakchan valleys in the Mergui district, lying on the Mergui rocks and occurring in the same order of sequence. Sethu Rama Rau

[320] Page records plant and fish remains in the shales (Gen. Rep. Rec. 38, 59) (1909).

[321] Rec. 26, 152-153 (1893).

divides them into two groups. The lower consists of soft, white sandy shales with plant remains, ferruginous sandy shales with ripple-marking, and carbonaceous shales with thin layers and lenses of lignite ; the upper group comprises white or grey friable sandstones overlain by a brown ferruginous variety which is capped by a ferruginous conglomerate and gravels with boulders and pebbles of argillite and pebbles of white vein quartz.

In the Lenya river the total thickness of the beds has been estimated to be 500 feet. Here the Tertiaries resemble in many respects the Mepale oil shales of the Amherst district, which have yielded identifiable plant remains of late Tertiary age.[322] Some of the Lenya shales, although not actually ignitable, burn with a bright flame in a Bunsen burner, emitting odorous fumes.[323]

Here may be considered the synclinal basins of beds including oil shale in the Amherst district examined by Cotter who has suggested for them a late Tertiary age. This formation, resting unconformably on older rocks, is of fresh-water origin and is found to the east of the Dawna range. The main basin of Htichara occupies a broad open valley drained by the Mepale river and situated between the Dawna and the Choehko Taung, the latter being a range branching south-eastwards from the Dawna. Further east Cotter reports two or three additional basins of the same rocks along the Thaungyin river which here forms the boundary between Burma and Siam.[324]

In the Htichara basin the upper Tertiaries rest on red sandstones belonging probably to the Kalaw series or on the Kamawkala Limestone (? Triassic) along the eastern flank of the fold, and on the Dawna gneiss (Archæan) to the east ; the dip is usually gentle, rising to 15° and 20°, but a certain amount of gentle undulation is seen in the basin. In this syncline the beds are divisible into two well marked groups, the lower of which has much in common with the Irrawadian.

The lower group, omitting a conglomerate which Cotter at first placed at its base but afterwards assigned to the top of the Kalaw Red Beds, forms a ring round the upper group in the Htichara basin, is well exposed in the Kamawkala gorge to the north, and has been recognised to the west of Phalu on the Thaungyin river further south. It comprises sands, generally loose and current-bedded, conglomerates and boulder beds ; fossil wood of the same kind as that found in the Irrawadian is of sparse occurrence, but some large logs were observed on the banks of the Thaungyin near Phalu. The sands contain pebbles and boulders derived from quartz veins, quartzites, quartz-mica schists, tourmaline-pegmatites and granite-gneiss. In places the pebbly sands grade into loosely compacted conglomerate or gravel. The boulders of the boulder beds usually show a decrease in size upwards, a diameter of 1 foot being common in the basal layers. In

[322] W. N. Edwards, Geol. Mag. 60, 159-165 (1923).
[323] S. S. Rama Rau, Mem. 55, 31 (1930).
[324] Rec. 55, 286-290 (1923).

several places enormous boulders, some of them 8 feet across, are recorded, similar to the erratics of Pakokku.[325] Massive beds of coarse arkose and grey or buff grits also form part of this sequence, and in two localities, not far below the top of the group are reefs of fresh-water limestone; one of the latter, found near Htichara, contains abundant fresh-water shells, among which the following have been determined by Annandale: *Acrostoma intermedium* Annand. *A. cotteri* Annand., *Vivipara gregoriana* Annand., *V. dubiosa* Annand., *Indopseudodon rostratus* Annand., *Lamellidens* (?) *quadratus* Annand., and *Indonaia bonneaudi* (Eydoux).[326] With the exception of the last living form, all the species are new, and the assemblage is considered to be not younger than late Tertiary.[327] From Mepale also comes a new fresh-water cyprinid fish to which Annandale and Hora have given the name *Daunichthys gregorianus*.[328]

The lower group passes conformably up into the upper, which consists predominantly of clay and shale, including oil shale, but with subordinate bands of sandstone; in addition there are present, especially in the basin on the Thaungyin north of Myawaddy, thin beds of fresh-water limestone, of both pure and impure type, with traces of melaniid and viviparid shells. The shales also are frequently fossiliferous and have yielded the remains of teleostean fish, dicotyledonous leaves, one fern leaf and a species of spider. Among the dicotyledonous remains W. N. Edwards has identified a leaf belonging to the Dipterocarpaceae (*Dipterocarpophyllum gregoryi* Edw.) a possible *Ficus* (*Ficophyllum burmense* Edw.), two leguminous fruits (*Leguminosites albizziformis* Edw.) and some wood. Like the animal remains, the vegetable are thought to indicate a late Tertiary age.[329] The outcrop of this upper group is covered with a dense growth of bamboo, forming some of the thickest jungle in Burma; this characteristic readily distinguishes it from the lower group with its open dipterocarpous forest of somewhat stunted trees. The distinction between the lower and upper groups is less well marked in the more easterly basins, where the upper includes frequent sands and beds of fresh-water shelly limestone. It is this upper group which appears to correspond to the possibly Pleistocene beds of the Shan States coal basins, but which contains no lignite itself. All the evidence points to a fresh-water origin for this upper group.

Oil shale, which is found interbedded with barren shale, is abundant in the lower part of this upper group, and is easily distinguished from the latter by its toughness, its capability of being cut into shavings with a knife, by its dark grey or brown colour, and especially by the peculiar smell it emits on heating. It may occur in thin papyraceous laminae or in thick layers, and there are all grades from completely barren shale to high-grade oil-shale. Some

[325] J. A. S. B., New Ser, 14, 419 (1918).
[326] Rec. 55, 97-104 (1923).
[327] G. de P. Cotter, Rec. 55, 287 (1923).
[328] Rec. 56, 204 (1924).
[329] W. N. Edwards, Geol. Mag., 60, 159-165 (1923).

half-a-dozen seams of economic importance have been noted, the best being 6.7 feet thick. The oil-shales on distillation yield up to about 20 per cent. of crude oil and at the same time useful quantities of ammonium sulphate. A good oil-shale, yielding 17.51 gallons of crude oil per ton of shale, yielded 22.31 lbs. of ammonium sulphate. The crude oil contains from 4 to 5 per cent. of naphtha, 25-35 per cent. of kerosene 40-45 per cent. of lubricating oil and about 10 per cent. of wax.

CHAPTER XXXIV

LATE TERTIARY AND POST-TERTIARY VOLCANIC ACTIVITY IN BURMA AND THE BAY OF BENGAL.

Lines of vents. **Central Line: Jade Mines area**—Loimye; Mabaw and Namyong; Katha district: Lower Chindwin and north Pakokku. **Main line:** Shin-ma-daung; Linzagyet; Songyaung; Silaung Taung; Minma; Natlabo, Natyindaung and Zinyein occurrences; Explosion Craters. **Subsidiary line:** Kyaukkadaung; Thazi; Inde; Okpo Letpan; Popa area; Thayetmyo and Prome; Tharrawaddy; Narkondam and Barren Islands. **Boundary Fault Line:** Kabwet; Kyaukse and Meiktila; Northwest Thaton. **Shan States Line;** Teng-yueh vents; Loi Han Hun; Mergui. The reported Pondicherry eruption.

Lines of vents.—The serpentine occurrences of Burma, of late Cretaceous or early Tertiary age, have already been considered. Volcanic activity in late Tertiary and post-Tertiary times in that country took place for the most part along a line of weakness which can be traced from the Jade Mines area southwards through Wuntho, the Lower Chindwin district, Mount Popa in Myingyan, Prome and Tharrawaddy, Narkondam and Barren Islands, to the great Sunda chain of volcanoes. It is a sinuous line of fracture and faulting which coincides generally with an axis of anticlinal folding; in places the line is either échelonned on itself or is accompanied by short parallel subsidiary fractures a few miles away from the main line. In one case at least a subsidiary line of crustal weakness crosses obliquely the main line.

Another sinuous tectonic line of a similar nature runs parallel to this central line but 70-80 miles further west, passing along the eastern flank of the Arakan Yoma and through the Andaman Islands; this is a much older line characterised by the serpentine intrusions already described, and does not concern us here. About the same distance east of the central line is another which extends through the Kabwet area of Shwebo and Mandalay, the Kyaukse district and the northwest corner of Thaton; it coincides with the main boundary fault along the western edge of the Shan Plateau. Over 140 miles east of Kabwet is another vague line of fracture within the Shan Plateau itself, passing through the volcanoes of southwestern Yunnan and the vent of Loi Han Hun in the Northern Shan States. The volcanic occurrences in Burma have been dealt with at length in all their aspects by H. L. Chhibber.[1]

CENTRAL LINE.

JADE MINES AREA.

Loimye.—Commencing at the northern end of the central line of disturbance, we have to consider some volcanic manifestations in the Jade mines area taking first the volcano of Loimye. Whether this

[1] "Geology of Burma", 286-507 (1934).

vent finds its rightful place here or belongs to an earlier Tertiary epoch is not known; it may be of Eocene age or it may be younger, but is described here for convenience sake. Initially it may have been a sub-aqueous centre of eruption.

Loimye, covered with almost impenetrable jungle and rising 5,124 feet above sea-level, is situated in an uninhabited region of northwest Myitkyina and has been described by Chhibber.[2] A conspicuous landmark in the Kachin hills of Kamaing, it is connected with a fault now marked by a line of salt springs. The oldest rock crops out in a N.-S. strip of greenish black basaltic tuff, which is in places interbedded with fresh-water Tertiary beds of unknown age,[3] and has shared in the folding of these sediments. The tuff is flanked on the east by gabbro which has intruded it, causing induration and bleaching. To the south of the gabbro is a mass of andesitic agglomerate, breccia and tuff which occupies the summit of the hill; mostly hidden beneath it are at least five lava flows of either basalt or augite andesite, one of the latter being vesicular. The summit is a dome of coarse greenish black volcanic breccia in which small angular or subangular blocks or lapilli of andesitic and basaltic lava are sometimes enclosed.

Mabaw and Namyong.—The Jade Mines area is not wanting in examples of volcanic activity which is definitely of late Tertiary or post-Tertiary age. From near Sankha village Chhibber describes an outcrop of siliceous agglomerate, having a width of less than half-a-mile and continuing north-eastwards for about three miles, past Mabaw as far as the Moschen Hka. Although called the Mabaw Agglomerate by Chhibber, the deposit is a bedded one and is interstratified with late Tertiary beds, the sequence being mostly horizontal but showing dips up to 10°; boulders of a Tertiary conglomerate are seen in the Mabaw deposit. The chief constituents of the latter, however, are boulders of rhyolite and rhyolite breccia, from one to five feet across, and water-worn boulders of serpentine, some of them over two feet in diameter; a few boulders of quartz-schist have also been noted. Chhibber suggests that the eruption, which must have burst through serpentine rocks, took place along a fault which forms the junction between the outcrop of the Mabaw deposit and that of the serpentine and is marked by salt springs.[4] The rhyolite breccia referred to is made up of angular fragments of rhyolite and serpentine in a fine mosaic of quartz and felspar; it is a porcellanous rock and not infrequently vesicular, the vesicles being due to the weathering out of the serpentine fragments.

Genetically connected with these rhyolites are occurrences of granodiorite, quartz porphyry and quartz veins. Three outcrops of the granodiorite have been noted, the largest, 3½ miles long, on the Saingmaw-Hwekha road, with its northern portion intruded into the

[2] Geology of "Burma", 295-296, 348-354 (1934).

[3] They are described as very like the coal Measures of Assam, their heavy mineral residues are said to be comparable with those of the Barail series of Assam (Eocene—Oligocene).

[4] Gen. Rep. Rec. 63, 101 (1930); "Geology of Burma", 298-299 (1934).

serpentine and its southern into the Tertiaries. In contact with one of the other occurrences the serpentine has been rendered schistose, and the Tertiaries baked and hardened.[5] The granodiorite shows all gradations from true granite to quartz-diorite. The quartz porphyry is seen as small injections in the granodiorite, while the quartz veins are found here and there intruding the Tertiaries. Additional types are a soda porphyry intruding the Tertiaries, and a syenite porphyry penetrating the serpentine.

In the neighbourhood of Namyong are several outcrops of andesite and basalt, the volcanoes in each case having burst their way through Irrawadian sandstones with quartz pebbles and fossil wood.[6] Hornblende andesite, hornblende-trachyandesite, picrite basalt and olivine basalt are among the types present; the largest outcrop of hornblende andesite is that of the hill Janmai Bum.

Katha district.—One of the largest igneous regions in Burma is the volcanic centre of Wuntho, bounded on the east by the Irrawaddy and on the west by the Mu.[7] The precise age of the outbursts is not known and may be anything from Eocene to late Tertiary. This group of old volcanoes, now represented by conical hills, domes or piles of lava with craters, is also associated with a line of salt springs probably marking the position of a fault and traceable for 60 miles. The central parts of the jungle-clad Mingin (Mangin) or Maingthon hills, which are from 30 to 35 miles across, are formed of quartz-diorite (granodiorite), while the surrounding country is made up of dark volcanic breccia, conglomerate and ash, tuffs and flows of basalt, breccia being predominant. These rocks and their ore accompaniments are somewhat unusual. From the central mass radiate dykes showing considerable differences from the parent diorite. Some of the volcanic beds are epidotised, and in the agglomerate are found occasional fragments of decomposing amygdaloidal andesite. Eastwards these basic igneous rocks are seen to traverse extensively a series of mica-schists with an easterly dip. The oldest volcanic rocks of the area are some stratified tuffs dipping at 30°.

In the volcanic beds are found not only the dykes closely allied in composition to the central diorite, but also pyritous and auriferous quartz veins consisting chiefly of felspathic quartz. On the west side an aphanitic vein composed principally of lath-shaped plagioclase, hornblende, relics of augite, and considerable quantities of granular magnetite and secondary epidote, has its cracks filled with argentiferous cerussite. Near Kyaukpazat, northeast of Wuntho town, a quartz vein in a country rock of well stratified tuffs and andesitic breccias has yielded in places chalcopyrite, pyrite, galena, franklinite and the rare telluride of lead, altaite.[8] Chhibber has suggested that the initial outbursts in this region were sub-aqueous.

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[5] Gen. Rep. Rec. 62, 111 (1929).

[6] Gen. Rep. Rec. 63, 101 (1930).

[7] F. Noetling, Rec. 27, 115 (1894); H. L. Chibber, "Geology of Burma," 354-355 (1934).

[8] Rec. 30, 110—111 (1897); J. Coggin Brown, Rec. 56, 85 (1924).

Shin-ma-tung is a breccia dome. Minletaung, four miles west of Wuntho, is a crescentic hill, the remains of a crater from which one side has been blown away. The isolated peak of Taung-thonlon (5,621 feet) forming the extreme northern corner of Katha and a few miles away from the Mingin range, may perhaps belong to this igneous suite ;[9] this, the highest volcano in Burma, has not yet been explored.

Lower Chindwin and north Pakokku.—Through the lower Chindwin district and north Pakokku the central line of vulcanicity is either échelonned on itself or is accompanied by a short parallel subsidiary line to the east. The igneous occurrences of this region are found on both banks of the Chindwin, that on the west bank being undoubtedly continuous with the line through Popa to the south and possibly also with that through Wuntho to the north. Accepting this view, the line of occurrences on the east bank of the Chindwin would form a subsidiary parallel accompaniment to the main line ; an alternate hypothesis is that the Wuntho manifestations are in line with the vents on the east bank of the Chindwin, and that this line is échelonned on the main Popa line. A third possible view is that the lines on both banks of the Chindwin are represented by two lines in the broad Wuntho area. Whichever of these suggestions may prove to be the correct one, there is unquestionably another short transverse subsidiary line of dislocation crossing the main line a little west of Shwezaye and carrying a number of explosion craters.

Omitting for the moment the cross-line just mentioned, the two lines of volcanic disturbance in the Lower Chindwin coincide more or less with two slightly curved lines of anticlinal folding, one of them on the west side of the river passing close to Shin-ma-daung and in a line with the Popa area to the south, the other 20-25 miles further east, on the east side of the Chindwin ; these lines trend approximately N.-S. but veer northwards to a little E. of N. and southwards to a little E. of S. A third tectonic line, parallel to these two and some 15 or 16 miles west of the Wuntho-Popa line, passes through the Tertiary inliers of Medin, Myaing, Pagan, Gwegyo and Wetchok (Yedwet) but is characterised by no volcanic phenomena. The Tertiary and Post-Tertiary volcanic rocks of the Lower Chindwin have been described in detail by Messrs. Pinfold, Day, Stamp and Chhibber,[10] and on this published account,[11] much of the following summary is based, beginning with the westerly line.

As we have seen, the Eocene beds (Pondaung sandstones) of north Pakokku have interbedded volcanic beds. The volcanic occurrences now under consideration, however, began in Pegu times and persisted into the Pleistocene or Recent epoch ; by far the majority of them belong to post-Irrawadian times. They form a well defined

[9] J. Coggin Brown, Rec. 56, 84 (1924).

[10] See also C. Burri and H. Huber, Schweiz. Min. Petr. Mitth. Band. 12. 286-344 (1932) ; and Sondhi's work reported in Gen. Rep. Rec. 61, 103-110 (1928).

[11] Trans. Min. Geol. Inst. Ind., Vol. 21, 145-225 (1927).

suite, the lavas ranging from rhyolites through andesites to basalts, while the hypabyssal rocks include acid and intermediate types.

MAIN LINE.

Shin-ma-daung.—The peak of Shin-ma-daung lies just within the western margin of a large exposure of Pegu rocks which is separated from a tract of Irrawadian beds on the west by a N.-S. boundary coinciding for many miles with a strike fault; this fault forms part of the western line of tectonic disturbance. For seven or eight miles a thin strip of Pondaung Sandstone and volcanic beds intervenes between the fault and the Irrawadian boundary. Northward, the volcanic beds comprise conglomerates and breccias of rhyolite which occur on the west side of the fault immediately beneath the basal Red Bed of the Irrawadian, for a distance of about six miles; they appear to represent a period of specialised volcanic activity which lasted until the deposition of the basal Irrawadian but which began in Pegu times since Barber has found tuffs and rhyolitic agglomerates clearly interbedded with the Pegu rocks of the area.[12] These Pegu strata, according to Barber, belong to the Shwezetaw Sandstone stage (Oligocene).[13] Immediately south of the beds described and situated over the line of the fault is a sheet of basalt 1½ miles long by over a mile in width, forming a high plateau-like elevation. The sheet, now split up into loose blocks, is thought to represent a flow emerging from a neck probably hidden beneath the centre of the sheet. The edges of the latter frequently form sheer precipices and the flow is of so recent a date that few of the blocks composing it have been disturbed. The youthfulness of the flow is confirmed by the way it has adjusted itself to local topographical irregularities, descending into small valleys and piling itself against summits which could not be overridden. Small intrusions of a doleritic rock have penetrated the Pondaung beds, mainly along the line of the fault, and belong either to this or an earlier volcanic phase.[14] To the west of Shin-ma-daung are four or five tuff cones, composed of coarse, andesitic tuff with local admixtures of more acid pyroclastic rocks.

Linzagyet.—About 19-20 miles north of Shin-ma-daung peak, on the north bank of the Yama Chaung, is a small mass of fine-grained basaltic lava which appears to have been intruded into sands of Pegu age, with the development of chiastolite near the contact; the intrusion is composed of a picrite basalt similar to one found on the other side of the river east of Monywa.

About 25 miles north of Shin-ma-daung, the uplands south of Salingyi include large masses of coarse-grained diorite, epidiorite, dolerite and dacite. The suite includes extrusives but the majority of the rocks appear to have been laccolithic intrusions into the Pegus. The rocks have suffered pronounced dynamo-metamorphism accompanied by extensive mineralogical changes, the chief of which are the

[12] Gen. Rep. Rec. 60, 87 (1927).
[13] Mem. 68, 137 (1936).
[14] Mem. 68, 132-134 (1936).

saussuritisation of the felspars and the uralitisation and epidotisation of the ferromagnesian constituents. Barber also records an intrusion of a granitic rock into typical diorties near Saga, and the penetration of coarse diorite by a dyke of pegmatite southeast of Kyaunggon.

A few miles to the northwest of Salingyi and two or three miles north of Powin Taung is an outcrop of glassy hypersthene andesite whose relationships to the surrounding rocks is unknown. Powin Taung, some eight miles from Salingyi in the same direction, has the appearance of a lava-capped plateau. This hill and the neighbouring Ingyin Taung consist of andesites, rhyolitic agglomerates and fine-grained ashes and tuffs interbedded with the Pegu series, together with intrusions of coarse diorite and mica porphyry. The ashes and tuffs have developed sericite slaty cleavage and a marked schistose appearance, as a result of the high degree of metmorphism brought about by the intrusion of adjacent diorites. Locally the andesites have been silicified and the vesicles of the amygdaloidal rock have been filled with chalcedony.[15]

In the same neighbourhood, *i.e.*, between Yinmabin and Ywashe, a village on the west side of the Chindwin facing Monywa, are three very conspicuous conical hills on the south bank of the Yama Chaung, and two other hills southwest of Ywashe, all of them composed of white and bluish grey rhyolites, rhyolitic breccias and indurated tuffs. Veins and botryoidal masses of hematite, as well as veinlets and impregnations of malachite and azurite, are found in these intrusions.[16] Close to the group on the Yama Chaung are rhyolites bedded in the Irrawadian and dipping steeply to the south. From the outside, the group of hills southwest of Ywashe, known as the Letpandaung, presents the appearance of a fluted cone in which denudation has reached a mature stage; from the inside, according to Barber, the hills show a marked crateriform disposition.[17] The copper-ores, malachite and chalcanthite, occur as vein minerals in the rhyolitic agglomerates and tuffs of the Letpandaung hills and have been for a short time exploited.[18] There is good reason to conclude that all these acid rocks are not younger than late Tertiary, a conclusion confirmed by the mature denudation they exhibit.

A little further up the Yama Chaung on its north bank are two small elevations known as the Myayeik Taung, part of a flat plateau-like escarpment with a precipitous face to the west. Among the rocks which compose the hills are an indurated quartz grit, a white quartzite and a scoriaceous silicified rhyolite. To the southwest are masses of epidiorite resting against a holocrystalline rock of white felspar and small black mica crystals, the felspar of which has decomposed to an intensely white clay in which the unaltered crystals of black

[15] Gen. Rep. Rec. 60, 88 (1927); H. L. Chibber, "Geology of Burma", 382-383 (1934).

[16] Gen. Rep. Rec. 61, 105 (1928).

[17] Gen. Rep. Rec. 60, 90 (1927).

[18] Gen. Rep. Rec. 60, 27 (1927).

mica are sharply contrasted;[19] this rock is exposed on both banks of the Yama Chaung and appears in one place to have been intruded into Pegu sands.

The Kyaukmyet hills are made up of very compact rhyolites and quartz porphyries with interbedded quartzites. A liparite from this locality, described by Kelterborn,[20] must originally have been vesicular, though the cavities are now filled with a coarse-grained quartz mosaic; the rock has undergone silicification.

Songyaung.—On the west bank of the Chindwin opposite Alon is a low N.W.—S.E. hill with gentle slopes on all sides except the north, where its scarp of about 100 feet abruptly overlooks a shallow lake which occupies the site of an extinct volcanic crater. The rocks found in the hill by Sondhi have for the most part a general dip towards the south. They include a highly jointed and comparatively fresh olivine-basalt which in places is highly scoriaceous, a six-foot bed of lapilli cemented by a sparse amount of volcanic ash, and several beds of unconsolidated basaltic tuff; the latter contains quartz pebbles, sand and fossil wood in some quantity and also beds of fine and often finely laminated volcanic dust and ash. Sondhi deduces a rapid series of explosions of short duration and varying intensity.[21]

Silaung Taung.—Three or four miles north of the Yama Chaung is Silaung Taung, described by Sondhi, a plateau rising about 150 feet above the level of the surrounding country and capped by a horizontal 50-foot sheet of lava presenting vertical cliffs at its extremities. No neck is visible but it has probably issued from a vent concealed by the flow itself, which appears to be of very recent date. A few disintegrated blocks are seen around the immediate edges of the flow but are not found at any distance therefrom. Immediately south of Silaung Taung is an outcrop of coarse-grained granite superficially much decomposed.[22]

Minma.—Three or four miles northwest of Silaung Taung, rising from the Yinbo Chaung near Minma are the two plateau-like elevations of Myetthadaung, which are built up of quartzites capped by a lava sheet of dark, vesicular olivine basalt. Half-a-mile to the west is an outcrop of coarse-grained granite much decomposed at the surface.

Natlabo, Natyindaung and Zinyein occurrences.—North of Minma comes the cross-line of explosion craters. Before describing these, however, there must be mentioned two or three somewhat outlying occurrences which appear to belong to the Popa line.

Northeast of Minma, on the east bank of the Chindwin, some 3½ miles east of the Taungbyauk crater, a sheet of lava 10-20 feet thick at Natalabo village is seen resting on Irrawadian sands.

Further north are the hills known as Natyindaung, 11 or 12 miles north of Shwezaye, composed of olivine basalt, sometimes containing

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[19] Gen. Rep. Rec. 61, 106 (1928).
[20] Eclo. Geol. Helv., Vol. 19, 352-359 (1925).
[21] Gen. Rep. Rec. 61, 106 (1928).
[22] Gen. Rep. 61, 106-107 (1928).

iddingsite. The two hump-shaped hills are separated by an abrupt depression which is nearly at the level of the plain and is covered with quartz pebble gravel and debris of the igneous rock. The rock of one of the hills has a dyke-like appearance. The igneous rock is sometimes compact, sometimes exceedingly scoriaceous, and the age of its intrusion is definitely post-Irrawadian.

Further north, in the west of Shwebo, L. A. N. Iyer reports numerous basic flows, from 5 to 20 feet in thickness, in the sandstones and shales of the Irrawadian, in the Kyauktan Chaung, west of Yinyein; with these rocks are associated tuffs and occasional bands of clay. The beds have a low westerly dip.[23]

Explosion Craters.—North of the Yinbo Chaung comes the group of well known explosion craters first described by R. D. Oldham and afterwards by Messrs. Pinfold and Day.[24] There are some seven or eight craters occurring on a short line some 13 miles long and directed approximately N.N.E.-S.S.W. This line may cross but is evidently coordinate with the major line of tectonic weakness which passes through Popa and Shin-ma-daung. These craters of the Lower Chindwin occur on both sides of the river in the neighbourhood of the village of Shwezaye. The surrounding country is an open plain of alluvium or Irrawadian sandstone.

At the N.N.E. end of the short line, 6½ miles from the Chindwin at Shwezaye, is the crater of Ywatha, a shallow depression, some 150 feet in depth and about half a mile in diameter from rim to rim, sunk in sands belonging to the uppermost Irrawadian. The flat sandy bottom is partially under cultivation but there is no drainage outlet and the rim is intact. The inner wall, except along its base where it is hidden by talus, is still steep, and a slight coating of ash has survived on the surface of the western part of the rim; apart from this and the presence of sporadic blocks of basaltic lava strewn about the floor and over the outer flanks, subaerial denudation has, in the words of Pinfold and Day, done its best to remove all traces of the volcanic origin of the crater.

Twindaung, on the same side of the river and some two miles distant therefrom, is the deepest and best preserved crater of the group, though not the largest. From the river the ground slopes up to the crater rim, in the profile of a true volcanic cone. The inner wall of the crater is precipitous and on the north and west drops sheer to the lake which fills the depression; the rim of this wall is 300-400 feet above the level of the lake which in the centre is said to be 74 feet deep. On the eastern side of the lake is a narrow sloping shelf on which stands the village of Twindaung.

On the west and south, *i.e.*, towards the river, the wall of the crater is composed of ash beds and volcanic debris dipping sharply away from the rim. Northwards and eastwards, outside the crater, the country around is covered with deposits of volcanic ash now weathered to a red soil which is largely under cultivation. The outer

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[23] Gen. Rep. Rec. 65, 95 (1931).

[24] Trans. Min. Geol. Inst., Vol. 21, 156-225 (1927).

limit of this ejected material towards the northeast is marked by the village of Kyauk-o, which is 4½ miles from the crater's edge; here is a section showing horizontal deposits of coarse volcanic ash and lapilli and fragments of lava, a few quartz pebbles, between layers of fine mud-coloured ash. That this ejected material came from Twindaung and not from Ywatha, which is 2½ miles nearer is proved by the fragments of lava which Pinfold and Day found to have the unmistakable character of what forms part of the crater wall of Twindaung, and also by the individual crystals of black glistening hornblende and brown mica mixed up with the lapilli and ash. About 1½ miles away from the crater rim the surface of the ground begins to slope gradually upwards in the direction of the crater, with a maximum dip of some 10°, and is coated with a hard, whitish, vesicular, calcareous sinter in which are firmly cemented fragments of the lava and boulders of diorite and other igneous rocks; these beds emit a hollow sound when traversed by foot.

Two lavas have been recognised, one a grey basalt with phenocrysts of white felspar, very large black glistening crystals of augite with clear idiomorphic outlines and a few small clear crystals of olivine, and the other a less basic rock—a hornblende andesite with large conspicuous black phenocrysts of hornblende. Blocks of these lavas, some of them several feet in diameter, are scattered everywhere on the outer slopes of the volcano but are not found at any distance southwards. A markedly porphyritic character is peculiar to Twindaung as compared with the lavas of the other craters or of the neighbouring sheets. The southern part of the crater rim is capped by ash beds on which lie strewn blocks of the lava; below the ash the hill is composed of soft Irrawadian sands with abundant quartz pebbles. Over the lower slopes on the south are ejected blocks of various kinds including ultrabasic types of igneous rock; among those recognised by Chhibber are augite-peridotite, biotite-hornblende peridotite, hornblendite, pyroxenite, quartz-diorite, biotite-gneiss, hornblende-schist and a garnetiferous metamorphic rock.

Two or three miles south of the crater lip and trending eastwards from Wunbo, Pinfold and Day described a low ridge with a curved precipitous inward scarp facing the crater and separated from the more central volcanic ashes and debris by a narrow belt of alluvium. The top of this ridge is capped by ash beds dipping gently south, while below them occurs the assemblage of ultrabasic rocks mentioned above; fragments of the latter are found in the overlying ashes. These beds are thought to belong to an earlier eruption than that which outlined the present crater, but were ejected from the same vent. On both sides of the river bank at and opposite to Shwezaye are ash beds also belonging to this earlier phase of eruption; dipping in a southwest direction at 30°, they are made up of layers of lava fragments and occasional pieces of the ultrabasic rocks. The lava of these fragments is dark and differs from the porphyritic basalt and hornblende andesite of the crater vicinity; mixed with them are quartz pebbles and occasional pieces of fossil wood and small

blocks of hard quartz grit. These beds have been indurated to a hard rock through which the river Chindwin has carved its present channel.

Pinfold and Day conclude that, centred about the Twindaung crater we have "abundant evidence of volcanic activity during a considerable period of time, although the evidence suggests that the activity was periodic rather than continuous. For instance it would appear that the outlying accumulations of ash in a southerly and southwesterly direction are not associated with the latest activity, but represent the remnants of extensive ash deposits which were spread out over the neighbourhood prior to the formation of the existing crater. The general shape and curvature of these remnants suggest that the old crater occupied very much the same position as the existing one, and the mass of lava blown out during the final eruptions, part of which still exists as a wall in the present crater, was possibly a plug which filled the neck of the old vent." Denudation proceeded during the lull in activity, for the alluvial plain mentioned above had been scoured out before the commencement of the final period of activity; in this way the ash beds which form the southern rim of the existing crater dip steeply into this alluvial valley instead of resting upon the ash deposits of the older eruption. The earlier eruptions took place during the period which followed the close of Irrawadian deposition; on the other hand, ashes and fragments from the existing crater are scattered upon Irrawadian sands and alluvium alike and the final stages of eruption cannot have been earlier than sub-Recent. Messrs. Pinfold and Day are of opinion that the holocrystalline ultrabasic rocks which form such a prominent proportion of the ejectamenta from this volcano, especially during the earlier eruptions, may have been the differentiated hypabyssal representatives of the extruded lava.[25]

On the west bank of the Chindwin, some 2½ miles south of Shwezaye Taung is a group of three contiguous craters. The most northerly is that of Taungbyauk, sloping upto which from the west, north and east are accumulations of ash, which extend to the high ground on the river bank and have been deeply cut into by the Sinzwe Chaung half-a-mile north of the crater. This stream has exposed the pebble-bearing sand on which the ashes lie. The ashes, coated with calcareous sinter, are similar to those of the Twindaung vent and emit the same hollow sound when walked upon; mixed with the layers of ash and strewn over the surface are small quartz pebbles. The inner walls of this crater are precipitous and composed mostly of ash deposits with fragments and blocks of an olivine-basalt which has not the large phenocrysts of the Twindaung lavas; some of the basalt is vesicular. The floor of the crater, which is half-a-mile across at the rim and averages about 200 feet in depth, is partially filled by a small lake fed by fresh-water springs at its side.

The sourthern rim of Taungbyauk is no longer intact but has been partly obliterated by the ash deposits ejected by the middle and

[25] Trans. Min. Geol. Inst. Ind., Vol. 21, 163 (1927).

slightly younger crater, which has no lake and is less clearly defined than the others. The most southerly of the three, known as Twin, is as much as $\frac{3}{4}$ mile across but is very shallow relative to its width, average not more than 150 feet in depth. In this crater there is no wall of lava exposed, though fragments and blocks are strewn about the slopes; the rim is formed of ash beds 30-50 feet thick and these are spread over Irrawadian sands. Between the middle and the most southerly of this group is a hill, the highest point of the neighbourhood, which is built up of a great thickness of ash beds unassociated, in the opinion of Pinfold and Day, with the deposits from existing craters but representing remnants of older eruptions.

Two miles southwest of Twin is the compound crater of Leshe, through whose ashes the Yinbo Chaung has scoured a broad channel half-a-mile south of the rim. The depression is divided into three by cross ridges partly of volcanic ashes and partly of Irrawadian sandstone, and represents three craters which in their formation have interfered slightly with each other. The more easterly is the smallest and youngest; the middle one has a shallow lake. The depth of these craters is not more than 150 feet and the rims are ill-defined. There is no wall of lava, but ash beds, resting on Irrawadian sands, slope up gradually on all sides to the rim. About four miles southeast of Leshe and separated from it by the Yinbo Chaung is an isolated ridge of ash beds with a precipitous face to the north.

The absence of any recognisable flow of lava from any of the craters that have just been described is remarkable, especially as thick sheets of andesitic and basaltic lava are by no means infrequent in the near vicinity and must have come from some neighbouring vent. With these neighbouring lava sheets there is a corresponding absence of ash. The volcanic activity of this region in fact, appears to have been differentiated into two extreme types, one set of vents giving issue to gentle outpourings of lava, while the other set consisted almost solely of violently explosive eruptions by which the craters we have just been considering were formed. The material ejected by these craters shows no sign of appreciable heat or fusion; all the larger and nearly all the smaller fragments of lava thrown out are angular and often show sharp corners. Volcanic bombs, with their typical rounded and scoriaceous surfaces are rarely seen and invariably small. Nearly all the lava fragments seen, therefore, must have been produced by the breaking up of a cooled and thoroughly solidified lava. Further evidence of the explosive nature of these craters is seen in the absence of any lava cone or of any subsidiary cone in the centre of the crater. The last eruption was of great violence and seems to have ceased abruptly. Erupted matter was scattered to a great distance, only that small portion of it whose velocity was checked by friction falling in the immediate neighbourhood of the vent and thereby forming a well defined rim. Much of the ash and tuff from these vents is contaminated with sand derived from the Irrawadian and contains also coarse layer with numerous quartz pebbles from the same sedimentary rocks. Oldham suggests that

these eruptions were like that of Tarawera in New Zealand in 1886, when no illumination of the ascending steam clouds could be observed at night, owing, presumably, to the absence of any mass of molten rock in the neck of the crater and to a temperature which could not have exceeded that of a dull red heat.[26]

SUBSIDIARY LINE.

The subsidiary or échelonned line to the east of, and parallel to the main central line through Shin-ma-daung is characterised by volcanic outbursts which have left their mark at various points east of Monywa, along a fault which for a few miles forms the western boundary of a Pegu outcrop.

All the volcanic rocks on this easterly line, and in addition the basalt of Natyindaung on the main westerly line, appear to have intruded as sheets or necks into both Pegu beds and Irrawadian. Pinfold and Day remark on the absence of any effects of great heat on the intruded rocks, and conclude that the igneous masses may have intruded in a plastic condition at comparatively low temperatures ; in this feature they bear a curious analogy to the explosion craters. " That these masses were intruded after the structural outlines of the Tertiary inliers had been established is definite and, further, their position appears to have been largely determined by the lines of major faulting along which the majority of the occurrences are found ". The lavas of this line are all very similar.

The occurrences may be considered from north to south and have been described with the others by Pinfold, Day, Stamp and Chhibber.[27]

Kyaukkadaung.—Some nine miles east of Monywa, on the fault mentioned which here traverse the Pegu inlier close to its western boundary, is an elliptical hill with three blunted peaks. The hill consists of a cone of ultrabasic rock—a picrite basalt—about a mile long and ¼ mile wide, completely surrounded by Pegu rocks. The latter, to the south and on the west side of the main fault, dip steeply away from the core and at the contact show signs of crushing and in places scorching. The eastern peak is covered with a deposit of calcareous sinter in which are embedded blocks of the lava ; the latter are restricted to the talus slopes and stream-beds at the immediate foot of the hill and are not widely scattered. The lava boulders on the slopes are usually vesicular, whereas the rock of the core is compact.

Seven miles further to the northeast and three miles east of the main fault, between the villages of Thazi and Sulegon, is another narrow elliptical outcrop, half-a-mile long, of the same picrite basalt; yet another small occurrence is seen on the summit of the Pagoda hill E.S.E. of the main mass. In reality these occurrences are somewhat off the line under consideration.

[26] Rec. 34, 139-141 (1906).

[27] Trans. Min. Geol. Inst. Ind., Vol. 21, 172 (1927).

Thazi.—Five miles northwest of the last mentioned locality, on the main fault two or three miles north of Thazi village, is a conical hill of the same igneous rock lying at the junction of the Pegu, Irrawadian and alluvium. The steep hill-slopes are strewn with talus, among which are blocks of the lava; such blocks are confined to the immediate slopes of the hill.

Inde.—The most interesting occurrence along this line is seen about eight miles further north, on the line of the fault, where remains of a crater and deposits of volcanic ash are similar in every way to the explosion craters to the west, though lying on a different line of fracture; the nearest of the Twindaung group of craters is Ywatha, some 10½ miles distant. The pyroclastic material is concentrated about the main hill and its western spur, according to Pinfold and Day. Immediately south of the village of Inde are beds of volcanic ash which curve round to the spur of the main hill and are seen further south resting on Irrawadian sands; here they are 10-15 feet thick and consist of layes of coarse lapilli with occasional blocks of lava up to a foot across, intercalated between much finer material. The beds are not consolidated and in steep exposures spill into heaps of grey cindery powder. No wall or sheet of lava is exposed but strewn fragments are seen in the deposit of ash and calcareous sinter which cap the main hill and its western spur; these fragments consist of an ordinary olivine basalt. Northwards, blocks of lava strewn over Irrawadian sands extend farther than the ash beds. Southwards there is a subsidiary hill made up of ash beds resting on Pegu sands. South and east of the main hill the blocks of lava strewn over the Pegu beds are few.

The inward slopes of the main hill and its eastern spur present a precipitous face which is the relic of a crater wall; the north and west parts of the wall have been removed by denudation and the floor of the crater is now silted up.[28] The age of this volcano is clearly sub-Recent, and there appear to have been several consecutive explosive eruptions.

Four or five miles north of Inde, on the main road from Budalin to Ye-U a thin bed of ash, about 4 inches thick is interstratified with Irrawadian sands. The locality is in a line with the fault, the persistence of which is indicated by the sudden steepening of the dip. No sheet of lava is seen but on the high ground to the east are small blocks of olivine-basalt.

Okpo Letpan.—Further northeast, about seven miles north of Inde and to the east of the above mentioned road, is an isolated hump-shaped hill, standing 400 feet above the plain of Irrawadian sandstone and known as Okpo Letpan. It is composed of much decomposed pumiceous olivine basalt of moderate thickness, intruded into the Irrawadian sands and grits and dipping steeply to the north. The talus is confined to the immediate slopes of the hill.

Popa area.—Along the same tectonic line as that characterised by

[28] Trans. Min. Geol. Ins. Ind., Vol. 21, 176 (1927).

the Lower Chindwin volcanoes occurs a group of vents in Myingyan of which Mt. Popa is the most important.[29] The ejectamenta of this volcanic tract cover an area of approximately 500 square miles. The crater of Popa is situated on a line of crust-weakness extending S.S.E.'wards; from various points on this line have issued andestitic lavas which have built up a range of hills ending in the vicinity of the two adjacent villages, Zibyugon and Taungye. Two or three miles to the west is another line of disturbance marked by the tuff cone of Taungni and other points of issue; either on the same line or a little to the west of it is another short low range five or six miles east of Kyaukpadaung town. West of these hills and two miles northeast of Kyaukpadaung town is the isolated vent of Taungnauk. Finally from Kyaukpadaung itself a volcanic range stretches S.S.E.'-wards and south-eastwards for six or seven miles, beyond which, along the same line are two or three more centres of eruption. The line of his hills from Taungni S.S.E. 'wards passes eventually through the peak of Kyukaingma and terminates in the hill known as Pingadaw. According to Hallows tuffs are interbedded with the Pegu sandstones exposed in the Kyaukaingma anticline; tuffs have also been penetrated by a well in the Kabat anticline near Sattein, some nine or ten miles north of the Popa summit. The tuffs of these two areas represent the earliest volcanic beds of the Popa area.[30]

The lofty, triple-apexed cone of Mount Popa, 4,981 feet above sea-level and nearly 3,500 feet above the Dry zone plateau of Upper Burma, forms a very conspicuous landmark which remains for many hours in sight of anyone journeying up the Irrawaddy. Distant some 30 miles from the left bank of the river, Popa, with its rich black soil around its base is a veritable oasis in a sub-desert tract. The mountain is a typical volcanic cone with slopes concave towards the sky; it is known to the Burmans as a "firehill" (mi daung), but no historical record of actual volcanic disturbance is traceable. Needless to say, a number of legends have collected around this unusual physical feature. Disturbance commenced in Irrawadian times but most of the Lava flows and tuffs appear to be Recent.

The northern part of the crater wall is missing, the breach having been initiated probably by a final explosive paroxysm; the rest of the wall, with sheer drops of nearly a thousand feet on the inside, encloses a basin, about a mile across at the brim and some 2,000 feet deep, drained by a stream which has cut back through the northern gap, and the home of leopards, wild pig, barking deer and loud-voiced crickets. There is no crater floor but merely a deep ravine choked with the densest jungle and exposed only for a few hours daily to the sun's rays. The exterior slopes of the mountain are at first steep and evidently represent approximately the angle of repose of the breccia or agglomerate forming the highest deposit, which has the appearance of having been very little denuded, and is bare of vegeta-

[29] A description of this volcano by Mr. W. T. Blanford will be found in J. A. S. B. 31, 215 (1862).

[30] Gen. Rep. Rec. 41, 73 (1911).

tion except for some low cycads, small ground orchids and a little grass. Lower down the slope gets less and less, and passes into the ordinary plateau of Upper Burma; westwards and eastwards, however, a horizontal terrace intervenes between the hilly volcanic slopes and the plain of the plateau. A parasitic cone on the western slope forms the remarkably abrupt and precipitous hill of Taungkalat (Taung-gala). The two flanking terraces West and East consist of Irrawadian sandstone with an interbedded ash and conglomerate sheet near the top. The western terrace is between 1,800 and 1,900 feet above sea-level and the eastern terrace a little lower, but Irrawadian sandstone is found further up the mountain as high as the 2,600-foot contour, and no doubt reaches a higher level still beneath the volcanic accumulations.

The Kyaukpadaung hills commence to the south of the town of that name and extend S.S.E.'wards and south-eastwards for six or seven miles; there is then a gap in the volcanic outcrops for a mile or two, after which occur two or three more centres of eruption, the furthest one just above the village of Kywelu. These hills, as shown by Hallowes, are made up of tuffs and interbedded rhyolites and andesites all highly silicified.[31] The rocks are mostly whitish or cream-coloured and have in many places been so intensely silicified as to exhibit the structureless character of chert. Augite can be detected in some of the rhyolite. The tuffs often include fragments of rhyolite. A couple of miles to the northeast of Kyaukpadaung town is the isolated hill known as Taunknauk, which is composed of the same highly silicified rhyolites and tuffs, some of the former showing fluxion structure and vesicular texture. With regard to their age, the Kyaukpadaung rocks have suffered flexuring, and that the vents were active before the end of the Irrawadian period is indicated by the interbedding of some of the tuffs with Irrawadian sediments. Xenoliths of andesite have been noted by Chhibber in the tuffs and rhyolites of Kyaukpadaung and were thought by that observer to be derived from the andesites of the Kyauktaga hills; other facts seem to throw some doubt on this, however, and it is quite possible that the Kyaukpadaung rocks and the White Tuff, to be described below, are the oldest volcanic rocks of the neighbourhood, next, of course, to the reported Kyaukaingma tuffs of Pegu age referred to above. A chemical analysis of one of the Kyaukpadaung andesites gave 64.5 per cent. of silica.

Taungni, some nine miles south of the summit of Popa and two or three miles west of the Kyauktaga hills, appears to be a tuff cone made up of silicified and unsilicified tuff of much the same character and age as those of the Kyaukpadaung hills. The unsilicified tuff, a white chalky friable rock, is one of the most conspicuous rocks of the Popa area and gives rise to some of the most prominent features in the scenery of the mountain base. In places it is clearly interbedded with Irrawadian sediments; it is seen extending up several

[31] Gen. Rep. Rec. 40, 109 (1910).

of the small streams draining the western and southwestern flanks of Popa and crops out in the saddle between Popa and the Kyauktaga hills. The rock is peculiarly constant in character, consisting of a white ash full of lapilli of a pure white pumiceous lava and speckled with small flattish pebbles of a hard slate-blue clay. The white colour is largely due to kaolin derived from felspar and in places replaced by opaline silica. In the white mass have been recognised scattered fragments of altered rhyolite and andesite and of biotite and augite crystals. An easily eroded rock, it weathers in deeply carved, smooth, rounded channels and pot-holes, and the boundaries of its outcrop are always highly irregular. East of Sebauk at the southwest foot of Popa, it lies upon Irrawadian sandstone and has been bent into an anticline with dips of 40°-50° towards the southwest and of 10°-15° towards the northeast; here, where it lies upon softer rocks it is exposed in a steep scarp. Southeast of Sebauk its thickness reaches 40-50 feet. Overlying this White Tuff as much as 150 feet of Irrawadian beds have been measured in places, the basal layers of the latter containing pebbles of the tuff as well as abundance of fossil wood. As already noted, this tuff has shared in the plication of the Tertiary beds. According to Chhibber, it contains fragments of the older andesites of the Kyauktaga hills to be described in the following paragraph, but the correlation of these fragments is not beyond question. The White Tuff can be traced southwards from the slopes of Popa to Taungi and in all probability originated from this vent and not from the Popa crater.

From the southern edge of the Popa extrusions there extends S.S.E.'wards for some eight miles a wooded range of hills which may be conveniently named the Kyauktaga hills after one of the villages at their base, and which are capped with a lava of somewhat altered and frequently scoriaceous andesite. The jungle-clad hills S.S.E. of Taungni and in a line with that peak are built up of the same rocks and are included in this description. Along the range the andesitic lava overlies a tuff which is exposed at the base of the hills; northwards, however, in the saddle between these hills and Popa the lava, largely disintegrated into boulders, lies either upon Irrawadian sandstone or on the White Tuff. At the southern base of Popa it is overlain by a dark tuff and volcanic conglomerate very similar to that dealt with in the next paragraph. Both the lava and the tuff beneath it have shared in the folding of the Tertiaries and appear to have been bent into an anticline with dips up to 25°. The tuff is conglomeratic in places and includes fragments of Pegu sandstone.[32] At the southern extremity of the Taungni line of hills this andesite which is here rather thin, has flowed over Pegu rocks and wherever the cap of lava has been eroded away a small patch of Pegu beds appears from beneath.[33] Some of this older andesite contains amygdules of chalcedony and other material; of the former, the inverted crenate pattern of alternating white and semi-transparent layers is reminiscent of the pointed roofs of pagodas and the amyg-

[32] H. L. Chhibber, "Geology of Burma", 398.

[33] H. L. Chhibber, Trans. Min. and Geol. Inst. Ind., Vol. 21, 240 (1927).

dules are sold as "Pagoda Stones" for ornamental purposes. The rocks include a hornblende-andesite and some pyroxene-andesites. One of the latter, described by Chhibber, has both orthorhombic and monoclinic forms of the ferromagnesian constituent; the former is enstatite, the latter augite or diopside, and both are frequently altered to serpentine. An analysis of this rock by D. Waldie & Co. of Calcutta gave 58.1 per cent. of silica. Hauyne is a constituent of some of these lavas. In places these older andesites have undergone silicification; they are also sometimes seen to be injected with veins of a pale yellow garnet-scapolite rock. An acid spherulitic variety is reported half-a-mile east of Kyauktaga. A hornblende-andesite probably belonging to this suite is seen along the north side of the saddle which separates the Kyauktaga hills from Mount Popa; here it is exposed as a zigzagging outcrop overlying Irrawadian sandstone or the White Tuff.

About half-way between the Kyauktaga range occupation by these older andesites and the Kyaukpadaung line of hills is the low range lying to the northwest of Taungni and showing three isolated outcrops of silicified pyroxene-biotite andesite and biotite andesite. These lavas appear to be intermediate in type between the basic andesites of Popa and the acid andesites of the Kyaukpadaung hills, and are probably of the same age as the older andesites of the Kyauktaga hills.

On the mountain of Popa itself, the next earliest rocks appear to be some black conglomeratic tuff and ashes interbedded in the more or less horizontal Irrawadian sandstones which form the broad terrace carrying the village of Popaywa, on the W.N.W. flank of the cone; the outcrop of this interbedded detrital material can be traced round the northern to the eastern side of the mountain. It consists for the most part of a sandy ash, usually black or grey but sometimes a dirty white, with a layer of loose lapilli at the base, surmounted by a volcanic conglomerate or coarse tuff, with thin layers of ordinary mudstone here and there. At Sinzin to the northeast, Chhibber notes that the horizontal bedding in the ash is so fine and regular that steps up to the pagoda have been hewn out of it. This deposit rests unconformably upon a surface of the Irrawadian and has evidently filled up old stream-beds in the latter, since its thickness varies greatly and rapidly, and traces of old worn-down Irrawadian cliffs are distinguishable in more than one place. The ash in places contains fossil wood—a characteristic constituent of the Irrawadian—and the conglomerate pebbles, mostly of lava, which vary from about ½ inch to two or three inches across, but sometimes reach over a foot in diameter. The Irrawadian sandstone upon which the ash rests is pebbly and iron-stained and crowded with fossil wood often in large trunks; it was evidently a land surface similar to that which this deposit forms at the present day. Between this volcanic detritus and the surface of the terrace, there is at most 90 or 100 feet of Irrawadian sandstone. If any reliance can be placed on the identification of some small unfossiliferous inliers of supposed Pegu rocks in the vicinity,

we have some rough indication as to the particular level at which these ash beds occur within the Irrawadian series; these doubtful inliers occur at about the 1,300-foot contour and an allowance of 100 feet for folding would place the interbedded ash and conglomerate about 600 feet above the local base of the Irrawadian. It is calculated that they lie at a higher level in the Irrawadian sequence than the White Tuff. Similar soft black ash, conglomerate and loose friable tuff containing small lapilli of augite-andesite are seen beneath a lava flow on the southern flank of the mountain, resting either upon the old hornblende-andesite of the Kyauktaga suite, of which it contains pebbles, or upon Irrawadian sandstones or on the White Tuff.

The parasitic cone of Taungkalat, some 300 feet in diameter and protruding in the form of a sheer cylindrical mass of hornblende-dolerite for some 300-400 feet from the rubble of its own talus, lies well down the western slope of Popa, nearly three miles from the crater centre of the main vent. Surrounded on all sides by Irrawadian sandstone, which dips away from it, it rises to a height of 2,417 feet above sea-level. The rock is coarser and more even-grained than most of the igneous rocks of the area. The most abundant phenocrysts are of a greenish-brown pleochroic hornblende in elongated crystals usually decomposed. Phenocrysts of zoned felspars, mostly plagioclase, are numerous. The holocrystalline groundmass consists of laths of felspar with abundant granules of augite and magnetite. In some sections the felspar both of the phenocrysts and of the groundmass shows alteration to pale yellow or pale pink isotropic analcite. It is the crystals of specular iron-ore associated with this rock which are locally known as "Popa *sein*" or Popa diamonds. An analysis of the rock by T. Marrack showed 49.1 per cent. of silica, while Chhibber gives its specific gravity as 2.74. No flow connected with this vent has been identified, any that may have existed having probably been covered by later extrusions.

The western terrace, some 500 feet above the Plateau level and covering about six square miles, has a slight westerly slope, and is covered, especially around its margin, with numerous blocks of augite-andesite. These blocks, of all sizes and most of them water-worn, form a tumultuous assemblage lying upon an irregular surface of Irrawadian sandstone; in some the rock is slaggy, and a ropy structure is sometimes seen. These blocks are the disintegrated remains of one of the oldest flows and can be traced from the inner edge of the terrace for some distance up the mountain slope until they disappear beneath a younger flow of trachyte. In some places they compose a kind of conglomerate and show signs of exposure to stream erosion. The flow evidently took place prior to the formation of the terrace which at one time formed part of the flood plain of the old Irrawadian river flowing past the young Popa vent. On the southern slopes of the mountain we find the same conglomeratised augite-andesite lying upon either Irrawadian sandstone or the black ash; followed up the slope it disappears beneath the coarse agglomerate around the rim of the crater, and may belong to a separate flow.

The Taungbaw flow is described by Chhibber as a lava intermediate in type between an olivine-andesite and an ordinary olivine-basalt. It issued from the northern edge of the old crater and is now represented by a comparatively small remnant to the east of the village of Taungbaw and opposite to the present gap in the crater wall. Chhibber surmises that the greater part of this flow has been blown away by the disruption of the crater.

Another flow from the north side of the vent has left a small relic on the other side of Taungbaw and appears also to have been largely destroyed by the final paroxysm. This rock, showing 54.2 per cent. of silica, is a fine-grained hornblende-augite andesite with no olivine.

A later flow than the augite-andesite which issued westwards and reached the Poapywa terrace is a hornblende-andesite which flowed north-westwards and northwards between Popalon and Ngayangon over the augite-andesite; its upper surface is hummocky and irregular. It is probably this flow whose nose of consolidated blocks pushed over one another by the lava flood behind has been recognised by Chhibber beside the motor road from Welaung to Kyaukpadaung.

The eastern flow is a very extensive one, mostly of olivine-basalt with a silica percentage of 49.4, dark and vesicular.

High up on the western slope of the mountain is a pale grey trachyte which issued at a point now marked by the old Popa bungalow about 500 yards below the present crater rim. It flowed over the augite-andesite but its viscous material seems to have reached a short distance only and its slope is very steep. It is rough to the touch and, like the White Tuff, emits a hollow sound when walked upon. Small white crystals of kaolinised felspar are conspicuous in the rock which under the microscope also shows a few phenocrysts of augite in addition to those of felspar; the bulk of the rock, however, is fine in grain and holocrystalline, consisting of granular augite, felspar laths decomposed to calcite and granules of magnetite.

The "bedding" of the lava flows is distinctly visible along the inside wall of the crater, especially on the eastern side, ten feet being a common thickness. The rim of the crater is made up of volcanic agglomerate, an indiscriminate assemblage of ashes, cinders, bombs and angular blocks and fragments of lava of all sizes and descriptions compacted together by the agency of percolating water; augite-andesite, hornblende-andesite, basalt and trachyte are all represented among these ejectamenta, some of which are of a considerable size. When traced up the mountain the lava flows end approximately at the same level and often in a small ridge; the cone of agglomerate forming the top of the mountain, therefore, seems to have built itself up inside an older, larger and subsequently obliterated crater. The surface of the eastern terrace, which covers a larger area than the western, is, with the exception of its southern portion, strewn with a breccia consisting, like the summit agglomerate, of fragments of most of the other rocks, including augite-andesite and the older and younger hornblende-andesites; among them are a considerable

number of boulders of fossil wood. It is mainly, therefore, an accumulation of ejectamenta thrown out by explosions and may perhaps date from the truncation of the original cone.

Chhibber finds that the lavas of Popa reached as far north as the village of Legyi. Bombs are said to be abundant along the foot of the volcano facing the gap in the crater. Ejected blocks are found here and there scattered over the hill-sides and include hornblende rock, epidote rock and plutonic equivalents of the lavas such as gabbro and diorite. One of the youngest and most extensive deposits found round the base of the mountain is naturally a volcanic conglomerate showing sorting action and stratification; it rests most commonly upon Irrawadian sandstone or the White Tuff, and is younger than the Plateau Red Earth. A greyish black volcanic alluvial soil is seen covering Pegu rocks to the east and both Irrawadian and Pegu towards the north and south for long distances; westwards this alluvium does not extend so far. Remnants of the ferromagnesian minerals of the lavas can frequently be recognised in this fertile surface accumulation.

Thayetmyo and Prome.—In the Pegu Yoma, not far from the alignment of the Popa line of tectonic disturbance, dolerites have been noted in four localities as small sills intrusive along the bedding planes of Pegu beds.[34] Three of these are well marked intrusions, one at Biyandi Myenettaung on the borders of the Thayetmyo and Prome districts 24 miles east of the Irrawaddy at Pyalo, a second at Lethadaung Myenettaung nearly 4 miles W.S.W. of the first, and the third at Tondaung Myenettaung 4½ miles E.S.E. of the second. All stages of alteration in the dolerite are seen, the final assuming the form of a black earth or "regur", after which the hills are named (mye-net-taung=black earth hill). Biyandi Myenettaung is a conspicuous conical hill, the lower portion of which consists of Pegu clays and sandstones. On Tondaung Myenettaung the Pegu sediments show thermal alteration at their contact with the dolerite, the clays becoming shales. The olivine of the dolerite in these intrusions has been appreciably serpentinised; some of it contains zeolites. Inclusions of palagonite have been noted by Chhibber. The fourth occurrence of black earth and altered dolerite is situated about a mile north of Biyandi Myenettaung, where the intrusion is in contact with baked Pegu clays.

Tharrawaddy.—On much the same tectonic line occur other sills of intrusive dolerite near Bawbin, some 17 miles E.N.E. of Zigon railway station in the district of Tharrawaddy further south.[35] The igneous rock is again an olivine-dolerite which has suffered serpentinisation and in some cases silicification; both palagonite and chlorophaeite have been developed in the rock. Several small outcrops of the dolerite have been mapped by Chhibber,[36] the rocks intruded being Pegu shales and sandstones dipping to the south. The contact shales have been highly baked and bleached, or show an incipient development of spots or contact minerals in places; in a few cases they

[34] H. L. Chhibber Trans. Min. Geol. Inst. Ind., Vol. 21, 333-336 (1927).
[35] H. L. Chhibber, Trans. Min. Geol. Inst. Ind., Vol. 21, 351 (1927).
[36] Trans. Min. Geol. Inst. Ind., Vol. 21, Pl. 44

have been changed to hornfels. Xenoliths of these altered shales and sandstones are to be found enclosed in the dolerite, while a lit-per-lit injection of the latter into the country rocks shows that the intrusion took place at comparatively high temperatures. In some of the streams the igneous rock has given rise to waterfalls.

Fourteen miles south of Ngaputaw on the Bassein River is the "Chauk-talon" (Kyauk-ta-lon) of Theobald, a boulder 6 feet across of greenish purple "trachyte" with small crystals of glassy felspar and olivine; from its small size it is probably a fragment from a volcanic vent in the vicinity entirely covered by alluvium.

Narkondam and Barren Islands.—The volcanic line can be traced through Narkondam and Barren Islands, east of the Andamans. G. H. Tipper found that, although there was evidence in the Andamans of a fold or thrust westwards, yet the submarine slope of the ground off the west coast was gradual while that off the east coast was steep, and thought the explanation of this might be a fault to the eastward, near which Narkondam and Barren Islands would lie.[37] Carpenter speaks of a "deltaic shelf" between the mouth of the Irrawaddy and Narkondam; its formation may, perhaps, have been assisted by submarine or submerged vents.[38]

Narkondam ("Nacondaon") is plotted, though not very correctly, on an ancient Dutch map engraved in 1595 ("Itinerario Voyage ofte Schipvaert, Van Jan Huygen Van Linschoten naer ofte Portugaels Indien, etc." Amstelredam); of this an English translation, including the map, was published in 1598 in London ("John Huighen Van Linschoten, his Discourse of Voyage into ye Easte and West Indies"). A second small and nameless island on the same map, marked about 15 miles east of the Andamans, is probably meant for Barren Island. The latter was sighted by Captain H. Gough of the Stretham in 1708; it was called "Monday Island" by Cheyne, "Alto" by Captain Baker and C. Alves, and "Illha Alta" (High Island) by the Portuguese.[39]

Narkondam.—The oval island of Narkondam (perhaps from Narak, Hell, and Kundam, a pit) rising like Barren Island further south abruptly from comparatively deep water in the Bay of Bengal, is situated a little under 160 miles from the Irrawaddy delta coasts. Rising 2,330 feet above the level of the sea and some 6,000 feet above the sea-floor, it has an area of about 2¾ square miles, a roughly conical shape but no relics of a crater. The shallower soundings round its base may be partly the result of greater accumulation of sediment derived from its denuded slopes, so that it has probably been just as large if not larger than its neighbour, Barren Island. Its sides are deeply scoured by ravines and its coast has been eaten back into cliffs some of which tower for several hundred feet above the sea;

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[37] Gen. Rep. Rec. 35, 48 (1907); G. H. Tipper. Mem. 35, pt. 4, 16-17 (1911).

[38] Rec. 20, 48 (1887).

[39] F. R. Mallet, Rec. 28, 22-34 (1895); for a picture of the island in 1789 see Pl. 1.

most of the island is covered with dense jungle.[40] There is little or no volcanic ash but agglomerate composed of rounded and angular lava fragments of every size up to 3 to 4 feet in diameter, embedded in a fine matrix, is exposed in some sections of the coast. For the most part the island consists of an acid hornblende-andesite for which H. S. Washington has used the term, hornblende-dacite; it is a compact or only slightly vesicular rock of very uniform composition, with about 61.2 or 61.3 per cent. of silica;[41] it is thus considerably more acid than the lavas of Barren Island. The absence of a crater suggests a domal form of eruption which, judging from the depth of the ravines excavated out of the lavas, must have taken place long before the historic period and no more recently probably than the latest flows of Popa.

Barren Island.—Seventy-five miles S.S.W. of Narkondam is the only recently active volcano of which the Indian and Burmese regions can boast, Barren Island, now dormant but known to have been active within the last 150 years. From the description of Mallet,[42] the top of the original cone appears to have been blown off and a new cone, now breached on its northwest side, built up within the old crater. Covering an area of a little over 3 square miles, the island has an irregularly circular shape and is about 2 miles in diameter. The wall of the old crater rises to a height of 700-1,000 feet above the sea and surrounds a slightly elliptical amphitheatre whose larger axis runs N.E.-S.W. with a length of about 9 furlongs. From the centre of this a cone of remarkably regular shape rises to a height of 1,015 feet above the sea-level. The depression between the slope of this cone and the inner slope of the amphitheatre has a maximum elevation of 300 feet above the sea, and is entirely occupied by three distinct lava streams. It is evident that the island was once much higher than it is at present, the outer rim marking the limit of a crater produced by some great paroxysmal eruption which blew away all the upper portion of the old cone. The bottom of this old crater must have been much below the level of the sea and, for some time before the new cone attained its present dimensions, the sea must have flowed round its base between it and the foot of the internal slope of the amphitheatre; there is no authentic record of anyone ever having seen this stage in the island's life-history, which is, however, represented in the older descriptions thereof. In 1789 when Blair saw the island, the sea did not penetrate into the amphitheatre which had everywhere been filled up to above sea-level; the volcano was then in active eruption, throwing out blocks and scoriae. Possibly it had been visited at some earlier period before the hollow was completely filled up, and the only record left of this visit is to be found in the description which was at one time current in text- books but which does not tally with conditions prevailing since 1789.

The portion of the volcano above sea-level is but an insignificant proportion of its whole bulk. Soundings have shown that the cone rises from a depth of 1,140 fathoms below the sea, and that the total

[40] A. Carpenter, Rec. 20, 48 (1887).
[41] H. L. Chhibber, "Geology of Burma", 439 (1934).
[42] F. R. Mallet, Mem. 21, 251-286 (1885).

height of the present cone is consequently some 8,000 feet and must have been 10,000 feet before the upper part of the outer cone was blown away.[43] At the time of Blair's visit there appears to have been no lava stream in the gap where the outer rim is breached, but in 1832 the lava was there, and still so hot that the water in contact with it was boiling. Since that date the flow has cooled down and the temperature of the water which percolates beneath the lava and issues as a spring on the sea shore has steadily diminished at each successive visit, till in 1886 it was no more than 110° F.[44] It seems certain, therefore, that this lava flow was poured out some time between 1789 and 1832. Towards the southeast the slopes of the island belie its name by being well wooded. The perfectly symmetrical central cone has an even slope of 22° and is truncated at the summit from which a thin column of steam rises slowly into the air. The small crater at the top is only 60 feet across and about 78 feet below the highest points of the surrounding rim ;[45] its floor is covered with loose blocks of lava, scoriae and ash except towards the southwest where there is a solid mass of lava. Almost encircling the base of the inner cone are streams of lava, all with fissured and hummocky surfaces and covered with a dark rugged scoriaceous crust. Three flows have been distinguished, an eastern, southern and northern, all of them consisting of an olivine-basalt very similar to that found at Twindaung in the Lower Chindwin district or to one of the Popa lavas. The largest flow was the southern which, issuing from a point a little more than half-way up the cone, poured down the side and found its way to the sea along the amphitheatre valley. The northern flow broke through about 250 feet below the present crater rim and has left a solfatara at this point whence steam issued ; the molten rock flowed down into the amphitheatre and over the older southern flow. The age of the eastern flow, with reference to the other two cannot be determined with certainty, since it does not come into contact with either.

The old cone is largely made up of lava, more or less vesicular and most of it a doleritic basalt in which olivine is frequently seen ; an average sample yielded 49.55 per cent. of silica and has a specific gravity of about 2.8. Specimens from the vicinity of the landing-place on the west of the island were found by H. S. Washington to consist of a porphyritic augite-andesite with some olivine, analyses showing about 53 per cent. of silica and over 2 per cent. of titania.

Both outer and inner slopes of the old crater wall are strewn with ash ejected from the central cone ; as an effect of the southwest monsoon, most of this material has accumulated to the north and

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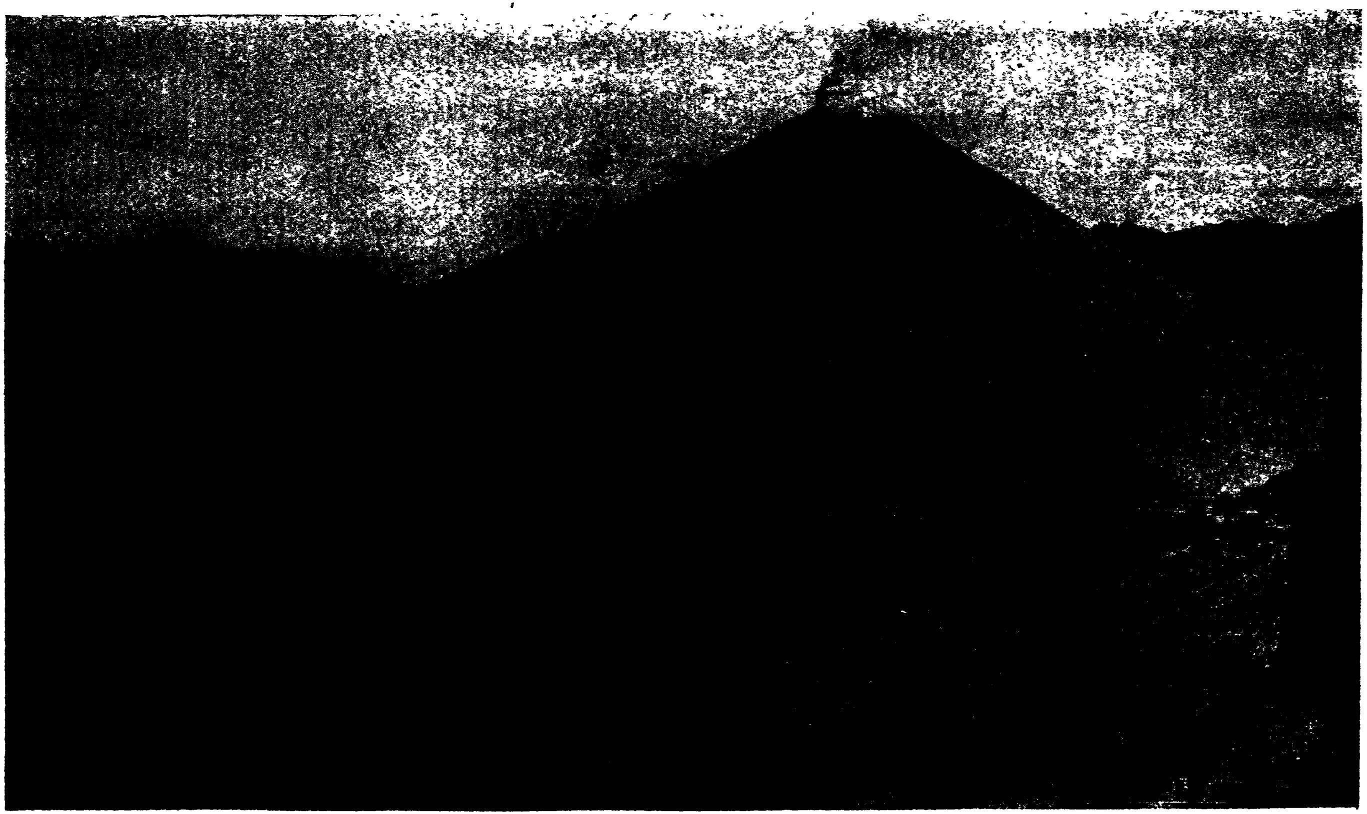
[43] A. Carpenter, Rec. 20, 48 and 46, note 3 (1887).

[44] Rec. 20, 48 (1887).

[45] Officers of the Danish Corvette, "Galathea" in recording their visit to this island in 1846, give the depth of the crater as 40 feet and its diameter as 15-16 feet, they speak of suffocating sulphurous fumes, and report that the floor of the crater was burning hot under their feet in places (Rec. 41, 218 (1911).



THE CENTRAL CONE OF BARREN ISLANDS.

northeast. This newer ash can be distinguished from older ash by its black instead of dull red colour.

Springs of hot water, which are gradually cooling, issue in numerous places from the shingle of the shore between the cliffs of ancient lava and the recent flow near the landing-place. Since the latest emission of lava the volcano has been seen in activity by several observers.

In a line with Narkondam and Barren Islands and some 80 miles S.S.W. of the latter is a roughly elliptical submarine bank, which may possibly be all that remains of a third volcano.

Continuous southwards with the line, we have been considering, is the great Sunda chain of volcanoes running through the volcanic ranges of Sumatra and Java and including the vent of Krakatua which, in 1883, was the scene of the most violently explosive outburst known.

BOUNDARY FAULT LINE.

So far the volcanic occurrences discussed all belong to the main Popa line of disturbance. It is now necessary to turn attention to the line of the great "Boundary Fault" further east, on which lie the volcanic areas of Kabwet, Kyaukse and northwest Thaton.

Kabwet.—After negotiating its third defile the Irrawaddy makes a sudden bend westwards for a short distance, past Kabwet, before resuming its southerly course past Singu[46] and in the direction of Mandalay. This abrupt deflection from its original channel has been caused by an outpouring of lava which now forms a plateau on the left bank of the river, 24 square miles in area, stretching from opposite Kabwet down to the village of Singu; it includes the Ywathit Reserved Forest, the haunt of wild elephant. A narrow strip of the old river sediments of Irrawadian age is exposed along the eastern edge of these volcanic beds, between them and the outcrop of the Mogok series which is here the country rock. Intrusive rocks connected with this extrusion are exposed on the right bank of the river northwest of Kabwet, a village which in the opinion of Sondhi, marks the position of a synclinal axis.[47] Among these intrusions is a long thin dyke of a rock intermediate between an andesite and a dolerite, intruded into the Pegus.[48] The area has been described by Dudley Stamp and H. L. Chhibber.[49]

As far south as the beginning of the lava plateau the Irrawaddy, according to Stamp and Chhibber, flows along the centre of a syncline of Irrawadian sandstone which is succeeded westwards by an asymmetric anticline with a steep westerly limb, involving both Irrawadian and Pegu rocks. On both sides of the anticline, but better displayed in the more gentle easterly limb, occurs the oldest volcanic rock of

[46] Not the oilfield of that name.
[47] Gen. Rep. Rec. 65, 92 (1931).
[48] Gen. Rep. Rec. 67, 49 (1933).
[49] Trans. Min. Geol. Inst. Ind. Vol. 21, 97-128 (1927).

the area, a lava flow interbedded in the Irrawadian. Its easterly exposure, traceable for over three miles, occupies a long dip slope, mostly bare of soil and vegetation, with a usually precipitous scarp; further to the east it underlies much of the country north of Kabwet village where it occurs here and there as small inliers in the Irrawadian and also as pebbles in the sandstones of this series. Where exposed the upper surface of this lava has become irregular and lateritised. Whatever it was originally, it is now a very soft, brittle, reddish grey rock, highly jointed in two systems of joints at right angles, and containing large numbers of small white, completely kaolinised felspars; the presence of serpentine makes it possible that rock was originally an olivine-basalt. Pillow structure has been noted but is by no means developed throughout the rock.

Thick intrusions of a later dolerite have invaded both the Tertiary rocks and the interbedded lava along the central part of the anticline. The largest intrusion, occupying the hill of Nat-taung, appears to be a laccolith in the eastern limb of the anticline; it is composed of an olivine-dolerite with analcite (teschenite), in which serpentinisation of the olivine has set in. Intrusions of a similar rock are also seen on the river bank at Singu and on the opposite side of the river a little further upstream. North of Nat-taung occur intrusions of typical olivine-dolerite with spheroidal weathering. The sodic character of these rocks is worthy of note, and is in contrast to the calc-alkaline affinities of the rocks in the Popa belt. On the authority of Chhibber, the intrusions are teschenites or anacite-dolerites and contain the typical purplish augite, whilst the extruded lavas are also of sodic types, with sodic plagioclase in many cases and always purplish augite. In fact, the minerals, soda-orthoclase, oligoclase-andesine, titaniferous augite, analcite, etc., are unique in this area; soda-orthoclase also occurs in the groundmass. Analyses of these teschenites and mugearites, as the soda-basalts have been called, show that they contain the highest percentage of alkalies among similar rocks in Burma, soda predominating over potash.[50]

The surface of the lava plateau of Singu is a flat plain, some 150 feet above the river, with a very gentle slope upwards away from the river towards the east as far as the sudden rise of the hill known as Lethataung. Lethataung is the highest point of a ridge which may mark the position of a fault along which extrusion took place. This younger lava is found only on the left bank of the river and was poured out over the planed-off edges of the Tertiaries. It is an olivine-basalt usually highly vesicular, in places scoriaceous and often amygdaloidal; ropy and tachylitic surfaces are frequently seen. In spite of the forest it carries, this lava is remarkably fresh, though frequently covered with a scanty red soil.

On the western side of the third defile of the Irrawaddy, in Shwebo, the Irrawadian beds, which are here greatly disturbed, are cut through by long dykes and minor intrusion of dolerite. A highly

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[50] H. L. Chhibber, "Geology of Burma", 457-458 (1934).

decomposed amygdaloidal basalt is also to be seen interbedded with the sandstone.[51]

In the Shin-ma-daung range,[52] south of the Kabwet area, are beds of rhyolite-conglomerate and breccias apparently contemporaneous with the basal Irrawadian.

Kyaukse and Meiktila.—Occurrences of felsite and andesite have been noted by P. N. Datta in the districts of Kyukse and Meiktila, but their relationships to other rocks is not known. In Kyaukse the andesite is seen forming the eastern half of Mondaung and on the spur of Tanklet Taung which projects from it. Cotter records two varieties of the rock, one speckled with phenocrysts of altered plagioclase and smaller crystals of augite and plagioclase, and the other a uniformly dark grey rock with a similar composition and structure.[53]

Northwest Thaton.—To the main Boundary Fault-line belong the rhyolites and rhyolite tuffs found in the northwest corner of the Thaton district of Lower Burma. Arranged along a N.—S line these eruptions appear to coincide with a strike fault in the Tenasserim Yoma which is a continuation southwards of the Shan Plateau. The locality lies 7½ miles east of Mohpalin railway station, in the township of Sittang. Near Kyauktaga the Khawa Chaung has cut a gorge in these volcanic beds, which are exposed for several miles in an outcrop seldom more than half-a-mile wide and sometimes much less. The lava have flowed over sediments which may be Permian or Permo-Triassic in age[54], but, from their fresh condition and their similarity in every respect to the rhyolites of Popa (Kyaukpadaung), the Lower Chindwin and the Jade Mines area, they are considered with good reason to be post-Irrawadian. The shales and sandstones of the Palæozoic rocks have in places been highly metamorphosed and changed into hard argillites and hornfels. Among the volcanic rocks, tuffs predominate but have the same mineral composition as the rhyolites, consisting of rhyolite fragments in a siliceous matrix. The rhyolites, which are small and thin, show banded and fluxion structures and are sometimes vesicular. A flow breccia, described by Chhibber, includes fragments of baked shale welded with pieces of rhyolite.[55]

SHAN STATES LINE.

Teng-yueh vents.—Coming now to the most easterly of the three volcanic lines, we may begin with the mention of some vents near

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[51] Gen. Rep. Rec. 63, 103 (1930).

[52] Not the better known Shin-ma-daung of north Pakokku.

[53] Rec. 66, 57 (1932).

[54] Gen. Rep. Rec. 60, 83 (1927).

[55] The granitoid gneiss exposed in the Government Quarries at Mokpalin has been penetrated by intrusions of lamprophyre, including a hornblende variety (H. L. Chhibber, Journ. Burma. Res. Soc. 16, 166(1927). The age of these intrusions does not appear to have been established and may be greater than the igneous phenomena now under consideration. Mr. Leicester records the presence in both Thaton and Amherst on micro-diorites which he regards as melanocratic differentiation products of the granite (Gen. Rep. Rec. 61, 62 (1928): *Ibid.*, 62, 101 (1929).

Ieng-yueh in southwest Yunnan, a country which is a northward continuation of the Shan Plateau. One of them is She-toe-Shan (Haw-Shuen-Shan) which has been quiescent within recent times and on which denudation has made little impression; the lower part of this volcano and all the flows around it are made up entirely of a black, slaggy, pumiceous lava. Lao-Kuei-po, Tay-in-Shan and the Kung-po group of vents have been described by Coggin Brown and Burton.[56] Lao-Kuei-po, a very regular cone, which has, however, suffered a greater degree of denudation than She-toe-Shan, has ejected a lava made up of a very light pumice full of steam holes. Tay-in-Shan rises some 3,250 feet above the general level of the plain and is a prominent feature north of Teng-Yueh; from base to summit it is composed of black, slaggy, pumiceous lava. The Kung-po volcanoes form a group of the Puy type, and there are other vents in this region.

All the occurrences of this region are believed to be of late Pliocene or Pleistocene age, since both craters and rocks are of recent appearance, while the latter have taken no part in any serious earth movement, and have in some cases been poured out over later Tertiary lacustrine sediments.

Loi Han Hun.—Loi Han Hun, in the Loi Ling range, is a conical or dome-shaped hill rising about 700 feet above the surrounding plain, six miles north of Mong Yai, the capital of south Hsenwi State, close to the Man-sang coalfield. La Touche found that the lower part of the hill, with its gentle slopes, is made up of nearly horizontal Tertiary silts, while the upper steeper portion is a dome-shaped mass of dense, columnar basalt, with dykes of the same material radiating from it in all directions; these dykes are especially well-developed towards the west and northwest; where it is possible another focus of eruption or intrusion exists. There is no trace of a crater nor of any ash or tuff, and the whole mass is said to bear more resemblance to a laccolith than to a volcanic neck or pipe.[57] It may, on the other hand, be an example of a domal eruption, the energy of the volcano having been just sufficient to extrude the basalt now forming the upper part of the hill and to fill the surrounding fissures with the basalt magma.

The rock is a dense, fine-grained basalt, almost black in colour, with a specific gravity of 2.94; among the phenocrysts are crystals of olivine partly serpentinised.

Whether extrusive or intrusive, the lavas appear to be of post-Tertiary age. They have invaded Tertiary silts which have accumulated since the principal drainage features of the plateau were formed; the only fossils found in these Tertiary sediments are very recent in type, belonging to the fresh-water gastropod genera, *Paludina* and *Planorbis*. A specimen of amygdaloidal basalt with

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[56] Rec. 43, 173-228 (1913).
[57] Rec. 36, 42 (1907).

indications of a glassy base, picked up about two miles west of the central mass may be a relic of a flow.

Mergui.—The olivine-basalts of Medaw Island in the Mergui distritct may belong either to the line of Kabwet, whose rocks they closely resemble, or to the Shan States line. There is nothing in the shape of a neck or volcanic vent, and the Medaw basalts form a small plateau resting on rocks of the Mergui series, through a fissure in which they were probably erupted. This plateau, 200 feet high, is covered with laterite which yields a red soil carrying a dense forest with very thick undergrowth; it occupies the western part of the island, the eastern portion consisting of Mergui rocks. The lava, which in places is split into polygonal blocks by a well-developed prismatic jointing, is very fine in texture, sometimes amygdaloidal but usually compact; it is sometimes bedded. Some of the vesicles contain a greenish, fibrous chlorophæite. The age of the eruption is doubtful but since in one place it rests on laterite very similar to that in the valleys of the Little Tenasserim and Ngawun, the chances are in favour of its being late Tertiary or sub-Recent.[58]

The reported Pondicherry eruption.—Before leaving this subject, mention may be made of a submarine eruption said to have taken place in 1756 off the coast of Pondicherry, and reported to have thrown large quantities of ashes and floating pumice and to have formed an island half-a-league long and of the same breadth. No exact details of the locality are given, but the account is a very circumstantial one[59] and, unless a pure fiction, must refer to a true volcanic eruption if the material ejected is rightly described. If it had been a gas eruption similar to those seen today along the Arakan coast and in the islands of Cheduba and Ramri, the ejectamenta are not likely to have been ash and pumice. It may be noticed that the Admiralty chart of the Bay of Bengal marks a sounding of 5 fathoms at E. longitude 80°42′ and N. latitude 12°46′, with the remark, "doubtful": this position would agree sufficiently well with that indicated in the account, and the depth might well be that subsequently produced by the action of the waves. On the whole the probabilities are that the so called "ash and pumice" were wrongly described by unscientific observers, and that the phenomenon was one of the ordinary gas eruptions to which the Bay of Bengal is known to be subject, though situated unusually far to the west. It is natural that such eruptions should be visible and recorded only along the shallow coastal waters of the Bay. Eruptions in the deeper and more central parts might well be taking place, for their effects at the surface would be limited to the escape of gas which would not be likely to attract the notice of passing ships, since it would be unaccompanied by the formation of mud islands.

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[58] H. L. Chhibber, "Geology of Burma," 470 (1934).

[59] "Asiatic Annual Register", 1758, reprinted in Proc. A. S. B., Vol. 16: (1847)

CHAPTER XXXV.

ADDITIONAL PLEISTOCENE AND RECENT DEPOSITS, EXCLUSIVE OF THE INDO-GANGETIC ALLUVIUM.

Distribution. I. PENINSULAR REGION: Classification; Cuddalore Sandstones; Warkalli beds; Porebander Stone or Miliolite; Kurnool Caves; **Older Alluvial Deposits of the Peninsular Rivers**—Location—the Narbada valley—The Tapti and Purna valleys—The Godavari valley—The Penganga valley—The Kistna valley— Diamond gravels—Origin of the river plains; **East Coast Alluvium**; Evdience of Recent movement along the east coast; The smooth-water anchorages off Cochin and Travancore; West Coast Alluvium; Indications of subsidence near Bombay; The plain of Gujarat; The Rann of Cutch; Alluvium of Kathiawar and Cutch; Littorol Concrete of Bombay and Kathiawar; The coasts of India; Evidence of elevation and depression along the west coast. **Soils**: Red Soil; Regur; Peat; Phosphatic and manganiferous soils. Sources of Water in parts of the Peninsula. Saltpetre deposits. Loess and drift sand. **Evidence of a colder climate in the Peninsula. II.** EXTRA-PENINSULAR REGION OF INDIA: Country west of the Indus: The Volcanoes of Chagai; Alluvial deposits of the Northwest; "Erratics" of the Punjab; The Bannu and Derajat plains; Waziristan; The Salt Range lakes; Hazara. Certain Pleistocene and Recent deposits of the Himalaya: The Karewahs of Kashmir; The valley of Nepal; The upper Indus valley; Hundes. Alluvial deposits of the Himalayan foot-hills. River gravels of Assam; The "plungs" of Assam. **III.** BURMA: **Plateau Gravel and Plateau Red Earth**—Lower Burma—Upper Burma; Red earth derived from the Plateau Limestone. Type of drainage on the Shan Plateau. Sand Lodes. Cave Deposits. Coal basins and lakes. Evidence of upheaval and submergence along the coast. The Burmese Rivers. Tenasserim. Soil. **IV. Alluvial Gold.**

Distribution.—The post-Tertiary and Recent formations of India cover an immense area. They occupy the wide plains of the Indus, Ganges and Brahmaputra, and also large tracts of country south of the Gangetic and east of the Indus plain. No older formation is exposed throughout the greater portion of the alluvial lowland belt which fringes the east coast of the Peninsula, while sub-Recent accumulations cover a large area in Gujarat and form coastal belts some times of considerable width along other parts of the west coast. The most important and extensive of the large deposits found in the valleys of the Peninsular rivers and upon the fertile plains of the interior, is that of the great Indo-Gangetic plain which, with all the important and interesting questions it raises, will be deferred for a separate chapter.

The comparatively unimportant Tertiary beds exposed in the Peninsula belong to the older or middle and not to the youngest parts of the system, so that there is a marked break between the known Tertiary and post-Tertiary deposits of the region. In the extra-Peninsular area, on the other hand, the uppermost Tertiary deposits are largely developed and, as already pointed out, it is often difficult to say where the line should be drawn; the lower part of the Pleistocene of this region has been considered under the head of Siwalik.

I. Peninsular Region.

Classification.—In dealing with the Pleistocene and Recent deposits of India it is impossible to observe in every case a strictly chronological order, but in the following classification of the post-Tertiary Peninsular beds, they have been arranged as far as our knowledge permits in descending order of age :

7. Blown sand.
6. Soils.
5. Raised littoral accumulations of sand, shells, etc.
4. Newer alluvial deposits of the river valleys and deltas.
3. Older alluvial deposits of the Narbada, Tapti and other Peninsular rivers.
2. Cave deposits.
1. Pleistocene or doubtfully Tertiary deposits of the coastal regions.

Cuddalore Sandstones.—Along the coasts of the Indian Peninsula, an interrupted belt of sedimentaries is found beneath the band of low-level laterite which encircles the great southwardly jutting land-mass. These sedimentaries include the Upper Gondwana and Cretaceous beds of the Coromandel coast, both of which have already been dealt with, and younger deposits which vary in age from late Tertiary or Pleistocene to Recent.

Along the east coast of the Peninsula, from the neighbourhood of Rajahmundry for fully 600 miles southwards to the district of Tinnevelly, a peculiar formation, consisting chiefly of sandstones, grits and conglomerates, is found at intervals underlying the laterite and associated gravels which form a low slope on the edge of the east coast alluvium. Various occurrences of it are believed to exist north of Rajahmundry as far as the Hooghly estuary. Under the laterite in Orissa, for instance, is a sedimentary formation which may be the equivalent of the Cuddalore beds, and in all probability the latter are represented by some clays and sandy beds associated with the laterite of Midnapore.[1]

This sandstone formation has received several local names, but is now generally known as the Cuddalore Sandstones, named after the headquarters of the south Arcot district where it is well developed. It may belong to the Tertiary and both Pilgrim and Vredenburg have suggested that it is the equivalent of the Karikal beds of Burdigalian age ; whereas, however, the latter have yielded one of the most prolific Tertiary faunas of India, the only fossils found in the Cuddalore beds are trunks of silicified wood.[2]

Throughout the area in which it is found, the greater portion of the Cuddalore group consists of gritty and sandy beds, sometimes highly ferruginous, in various tints of yellow, brown, red and purple,

[1] Mem. 1, 268 (1859).
[2] Rec. 36, 322 (1907).

sometimes white or nearly so, and not infrequently mottled.[3] In some cases the rock is argillaceous, and occasionally thin bands of clay or shale are interstratified. The beds are as a rule ill-consolidated and rarely coherent enough to be used as a building stone. Bands of conglomerate occur.

The Cuddalore beds usually form a low slope, dipping at a very slight angle to the east, in the direction of the sea, and are, in most cases, much concealed by the deposits associated with the low-level laterite of the east coast; eastwards they disappear in places, with their capping of laterite, beneath the alluvium of the coast, but quite as often and especially in the more southerly outcrops, they terminate in a small cliff. On their west side they rest indifferently but always unconformably upon Gondwana, Cretaceous, Deccan Trap or metamorphic rocks, often terminating in this direction in a low scarp. Their outcrop is repeatedly interrupted by the broad alluvial valleys of rivers, while in some places they appear to be wanting altogether, as for instance south of Madras where they are absent for nearly 100 miles. Elsewhere they form a broad tract, usually sandy and infertile, raised above the general level; near Cuddalore the width of the belt is no less than 25 miles but generally it is much less.

From the paucity of exposures the total thickness of the Cuddalore beds can nowhere be estimated with accuracy, but is probably quite inconsiderable. The scarp in which they terminate westwards is sometimes as much as 100 feet high and the total thickness must be somewhat greater than this. They are practically undisturbed and have every appearance of being a comparatively young formation.

The age and mode of origin of the Cuddalore sandstones are obscure. The only fossils found in them are trunks of silicified wood, some of which is coniferous.[4] This silicified wood is especially abundant at Trivicary (Tiruvakarai), some 14 miles W.N.W. of Pondicherry, where trunks of large size occur; one of them measured 100 feet in length, while stems from 15 to 20 feet long and 5 or 6 feet in girth are not uncommon. They lie prone, imbedded in ferruginous grit. The Cuddalore beds are quite unconformable to the Cretaceous which they overlap in a most irregular manner; near Pondicherry, for example, they rest on beds of the Ariyalur stage, forming the plateau near the town, known as the Red Hills, six miles to the west, and west of the belt of marine Cretaceous, they lie on Utatur beds near Trivicary, while a few miles still further west they completely overlap the Cretaceous beds and rest on gneiss. Fragments derived

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[3] H. F. Blanford, Mem. 4, 165 (1863); *Ibid.*, 256 (1864); *Ibid.*, 10, 59, (1873), *Ibid.*, 20, 35 (1883).

[4] Described under the name of *Peuce schmidiana* (Schmid u. Schilden; Uber die Natur der Kieselholzer. Jena, 1855, pp. 4, 36). The genus *Peuce* is not universally acknowledged and is too ill defined to justify any conclusions regarding the age of the rocks in which it occurs. It has been suggested that some fossilised bones of *Bos* (*Buffelus*) and *Equus* picked up in and around the Kallamedu Nala in the district of Trichinopoly came from the Cuddalore beds, but it is not certain and there is no outcrop of the Cuddalores in the Kallamedu (C. A. Matley, Rec. 61, 346 (1928)).

from the Cretaceous beds and containing Cretaceous fossils have been found near Tanjore. Near Rajahmundry the Cuddalore sandstones overlie the Deccan Trap, Upper Gondwana rocks and gneiss. In the Tinnevelly district Foote found sub-Recent marine beds, containing only living species of mollusca, associated with grits which he believed to represent the Cuddalore beds. Such a correlation would place the Cuddalore beds probably in the Pleistocene; it is at least safe to conclude that they cannot be older than Upper Tertiary.

The origin of these rocks has been a subject of much cogitation. Occurring as they do, parallel to the coast, it is evident that they were formed near the shore when its general contour was much the same as it is now but the level of the land somewhat lower. It is natural to infer that the sea played some part in their formation, but the complete absence, so far as is known of all marine remains would in that case, not be easy to explain. Coarse sandstones and grits are usually unfossiliferous, but in beds which have undergone so little change some casts of shells at least would probably have survived in the more argillaceous strata, if they were of marine origin. It is impossible that the western coast of the Bay of Bengal can have formed part of a single river valley in Tertiary times, and it is equally impossible that stratified grits, sandstones and conglomerates, like those of the Cuddalore beds, can be a form of subaerial wash. The most probable explanation is that the Cuddalore beds are silts brought down by the many large rivers which debouch into the Bay of Bengal, mixed perhaps with a certain amount of wind-blown material, and distributed along the coast by lateral currents. Behind the sand-bars formed by the latter, lagoons and back-waters such as are seen along both the Coromandel and Malabar coasts today would have acted as depositaries for the silts.

Warkalli beds.—More or less directly connected with the Cuddalore sandstones and occupying a similar position beneath the laterite are the Warkalli beds on the west coast of the Peninsula.[5] Forming a coastal fringe some five miles broad and resting on Archæan rocks, they have been traced for about 22 miles in Travancore from a point four miles north of Quilon to another point the same distance south of Varkala (Warkalli),[6] sloping gently northwards until the capping of laterite is the only bed visible. The Warkallis appear to be largely of fresh-water origin and are said to attain a maximum thickness of 200 feet. They consist chiefly of current-bedded sandstones and variegated clays with intercalations of lignite.[7] The Warkalli cliff is described by Tipper as follows.[8] Beneath the thick capping of lateritoid material are dark coloured clays with iron pyrites and beds of lignite containing little altered logs of woods,[9] overlying an

[5] E. W. Vredenburg. Rec. 36, 321 (1907).
[6] T. H. Holland, Mem. 51, 180 (1926).
[7] C. P. Kumar and C. S. Pichamuthu. Quart. Journ. Geol. Min. Met. Soc. Ind., 5, 86 (1933).
[8] Rec. 44, 190 (1914).
[9] Some of the logs of wood in the lignite are said to have been so unaltered as to allow of pieces of furniture being made therefrom

old sea beach. The clay beds are so similar to those forming at the present day in the back-waters of this coast that it is impossible to resist the conclusion that they have originated in the same way.[10] The old beach at the base of the cliff is composed of a dark brown ferruginous grit made up very largely of grains of ilmenite, magnetite, garnet and monazite, the last occurring in some quantity. Similar minerals are found among the sand grains of the present-day beach, whose monazite content is evidently being enriched by the degradation of its older fore-runner. A similar section is recorded near Villenjen (Villenjam).

It is highly probable that the Warkalli beds accumulated in coastal lagoons and back-waters similar to those into which the rivers of Travancore and Cochin empty themselves today. The bar now separating each lagoon from the sea is sometimes broken down during the flood season, but in the winter at least these large bodies of water, elongated in a direction parallel to the coast, are completely cut off from the sea. While the set of the currents on the east coast of the Peninsula is from south to north, that along the west coast is strongly from north to south.

Beds having some resemblances to the Warkallis have been described, lying upon a denuded surface of the Trap and underlying the laterite, further north near Ratnagiri on the Bombay coast. They consist of a few feet of white clay with imbedded fruits and containing thin carbonaceous seams composed for the most part of leaves;[11] the beds are capped by ironstone and laterite.

Porbandar Stone or Miliolite.—On the coasts of Kathiawar and Cutch is a well developed, fine-grained limestone, largely employed as a building stone in Bombay and known either as "Porbandar stone" from the name of the port in Kathiawar whence it is shipped, or as miliolite from the abundance of the foraminiferal genus, *Miliolina*. The rock is made up of organic calcareous particles, mainly of foraminiferal tests, with a few oolitic granules and minute mineral fragments from neighbouring igneous rocks cemented by calcite; near the sea-coast it is not infrequently mixed with a large proportion of sand. It is essentially a Recent coastal deposit and in the eastern part of Kathiawar is only found near the coast; further west, however, the beds cover a large area and extend on to the Tertiary rocks and Deccan Trap. The beds attain a maximum thickness of about 100 feet; they are extensively false-bedded, a condition which may have been brought about by wind and not necessarily by water currents. Their immediate æolian origin has been conclusively proved by Dr. J. W. Evans and Mr. F. Chapman[12] who found that the organic particles are worn and polished, that the prevailing genera of foraminifera which have survived consist of those having a rounded shape and that larger forms are not represented. They may be regarded, therefore, as sedimentary littoral deposits which

[10] Rec. 15, 96 (1882).
[11] C. J. Wilkinson, Rec 4, 44 (1871); *Ibid.*, 15, 102 (1882)
[12] Q. J. G. S., 56 (1900), 559 and 584.

have been largely redistributed by the wind. Land shells, doubtless washed down by small streams or floods, have been noted in some of the more impure varieties; in these and in types containing a large proportion of true oolite, the material would appear to be predominantly of a sedimentary nature. F. Chapman concludes that the foraminifera afford no evidence of an earlier age than late Pliocene and, from the relations of a very similar rock found in Persia, Pilgrim prefers to regard the rock as most likely of Pleistocene age.[13] This miliolite is of widespread occurrence in and near the coast of the Persian Gulf, including many of the islands therein; in Qishm and Henjam it is almost horizontally bedded and interbedded with fine-grained sandstones as it is in parts of Kathiawar. The rock has been found also on the southeastern coast of Arabia.

Kurnool Caves.—In only one locality in the Indian Peninsula have ossiferous cave deposits been found, namely at Billa Surgam, a few miles north of Banaganpalli (Banaganpilly; Banganapalle) in the district of Kurnool. The caves are in the limestone belonging to the Kurnool series and situated at a higher level than the sediments of the present drainage; their floor is encrusted with stalagmite beneath which lies a red marl, full of animal bones, large and small, some of them showing traces of having been shaped by man. The fauna includes apes including *Presbytis* and *Papio*, several carnivores, one insectivore, bats, rodents, ungulates, an edentate, several birds and reptiles, toad and five species of mollusca belonging to the genera, *Helix*, *Bulimus* and *Cyclophorus*. The majority of the bones are strongly impregnated with mineral matter; others, however, although obtained from beds containing extinct species, show scarcely any alteration and are apparently of later age; these belong especially to fossorial rodents and carnivores. Many of the incisors of *Hystrix* and other rodents retain their original colour.[14] There are vast quantities of the bones of Chiroptera and small rodents, probably introduced by owls and quite indeterminable. A considerable number of the larger bones are said to have been gnawed by porcupines. The fauna comprises many living forms including the ape, *Presbytis* (*Semnopithecus*) *entellus* (?) Dufr., but includes five species which, though closely allied to living forms, are extinct: these are: *Viverra karnuliensis* Lyd., *Hystrix crassidens* Lyd., *Atherura karnuliensis*, whose genus is no longer found in India, *Rhinoceros karnuliensis* Lyd. (little altered)., *Sus karnuliensis* Lyd. and probably *Sus namadicus* Pilg.[15] Perhaps the most interesting feature is the occurrence of four types which, in the opinion of Lydekker, are identical with, or closely allied to, living African forms; these are a species of the ape, *Cynocephalus*, the wild ass *Equus asinus*, a species of *Crocuta* probably identical with one found in the Pleistocene alluvium of Trichinopoly[16] and an adentate apparently identical with the west

[13] Mem. 34, pt. 4, 55-56 (1908).
[14] R. Lydekker. Pal. Ind., Ser. X, Vol. 5, 25 (1886).
[15] Pal. Ind., New Ser., Vol. 8, No. 4, 64 (1926).
[16] G. E. Pilgrim, Pal. Ind., New Ser., Vol. 18, 153 (1932).

African *Manis gigantea* Illiger. The age of the extinct fauna is regarded as Upper Pleistocene.

OLDER ALLUVIAL DEPOSITS OF THE PENINSULAR RIVERS.

Location.—The various older alluvial deposits of the Peninsula deserve notice both on account of the area they occupy and of the organic remains some of them have yielded. Since the mode of accumulation and the distribution of the deposits are bound up with the life-history of the rivers, the latter subject may be considered simultaneously. The rivers of the Peninsula may be divided into two main groups; the first comprises the Narbada and Tapti, flowing westward and draining the central portion of the Peninsula, while the second includes the Mahanadi, Godavari, Kistna, Penner, Cauvery and several smaller streams, all flowing eastwards into the Bay of Bengal.

While extensive alluvial plains exist in the valleys of the Narbada and Tapti, those of the eastward flowing rivers, such as the Godavari, Kistna and Cauvery, are smaller and are said to be less well-defined. As remarked by Vredenburg, most of the observations made on the alluvial tract of the Upper Godavari refer to the neighbourhood of Nasik and Paitan, both of which are so close to the edge of the alluvial area that the frequent outcrops of underlying rock noted at these localities do not affect the possibility of the existence of a deep basin towards the centre of the alluvial plain. The great depth locally attained by the older alluvium of the Narbada was never suspected before it was revealed by the Sukakheri boring near its southern edge.[17] Recent borings near the mouth of the Godavari show shallow depths of alluvial material.

The Narbada valley.—In the Narbada valley the principal plain stretches from Nimawar in Indore to Jubbulpore, a distance of more than 200 miles, and varies in breadth from 12 to 35 miles. The same deposits continue northeast of Jubbulpore for another 80 miles but the outcrop is much cut up by protruding *inselbergs* of gneiss and other older rocks. There is a smaller plain further down the river, extending for about 80 miles from Barwai (Barwaha) to the Harin Pal south of Bagh, but it is comparatively ill marked, and its alluvial deposits are believed to be much shallower and, so far as is known without mammalian remains. Both the Narbada plains are closed on the west by rocky and hilly country, through which the river has cut a steep channel; the deposits of the upper basin are known to have a maximum depth considerably lower than the river bed at the point of exit, so that the plain lies in a great rock basin.

Chiefly in consequence of the mammalian bones found therein, the alluvial deposits of the Narbada valley have received far more attention than similar formations on the banks of the other Indian rivers.[18] The great plain mentioned as extending from Nimawar to

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[17] Rec. 33, 38 (1906).

[18] Mem. 2, 279 (1860); *Ibid.*, 6, 227 (1869); Rec. 6, 49 (1873); H. B. Medlicott, *Ibid.*, 8, 66 (1875).

Jubbulpore is composed chiefly of a stiff, reddish, brownish or yellowish clay, with numerous bands of sand and gravel intercalated. *Kankar* abounds throughout the deposit, and pisolitic iron granules are of frequent occurrence in the argillaceous beds. Occasionally pebbles and sand are found cemented together by carbonate of lime into a hard, compact conglomerate; this rock is especially developed at the base of the alluvial deposits, and is often found forming a coating over the underlying floor rock, not only in the Narbada but in many other river valleys. The clay is frequently quite devoid of stratification, but appears never to attain any great thickness without sandy layers intervening. In a boring at Sukakheri, north of Mohpani and south of Gadarwara railway station, throughout a thickness of nearly 500 feet no change of importance was detected in the beds; by far the greater portion of them consisted of clay with calcareous and ferruginous grains, sand and pebbles being found occasionally throughout. The bottom of the borehole was in lateritic gravel, and it is probable that the country rock lay not much deeper. Between Hoshangabad and Narshinghpur, old river terraces rising some 120 feet above the stream, according to H. de Terra and P.T. de Chardin give the following generalised section:[19]

4. Upper pink concretionary clay.
3. Upper gravel and sand.

—— *disconformable break* ——

2. Lower red concretionary clay.
1. Basal conglomerate.

The basal conglomerate is coarser and more coherent than the gravels of No. 3, and the clay of 2 is more intensely coloured and richer in concretions than that of No. 4. Mammalian bones were obtained by these observers from the base of No. 3, *i.e.*, near the disconformity, while prehistoric implements were found to be abundant in the layers of gravel. The basal conglomerate appears to rest upon a bed of old laterite.

Of the shells and bones found in the Narbada deposits the following have been determined:[20]

INVERTEBRATA.

LAMELLIBRANCHIATA.

Unio corrugatus ? Lam. var.,
Unio indicus,
Unio aff. *shurtleffianus*,
Unio marginalis Lam..
Corbicula aff. *striatella*.

GASTROPODA.

Melania tuberculata Mull.,
Viviparus (*Paludina*) *bengalensis* Lam.,

[19] Proc. Amer. Phil. Soc. 76, 820 (1936). The authors suggest that 1 and 2 may be the equivalent of the Boulder Conglomerate of the Siwalik series, and 3 and 4 the representative of the Potwar silt.

[20] G. E. Pilgrim., Rec. 32, 214 (1905); *Ibid.*, 35, 120-121 (1907); *Ibid.*, 51, 366 (1920).

Viviparus (Paludina) dissimilis,
Bythinia cerameopoma (Benson) (doubtful; specimens lost),
Bythinia pulchella (Benson) (doubtful; specimens lost),
Bulimus insularis Eh.,
Lymnaea acuminata Desh., (doubtful; specimens lost),
Planorbis exustus,
Planorbis compressus Hutt. (doubtful; specimens lost).

VERTEBRATA.

REPTILIA.

Pangshura tecta Bell (*P. flaviventris* or *Emys namadicus* Theob. found in Indian rivers of today),
Batagur cf. *dhongoka* Gray,
Trionyx cf. *gangeticus* Cuv.,
Crocodilus sp.

MAMMALIA.

Ursus (Helarctos) namadicus Falc. & Cautl.[21],
Bubalus (? *Buffelus*) *palaeindicus* Falc. (allied to the modern Indian buffalo),
Boselaphus namadicus Rut. (related to the modern "Blue Bull" or *nugai* (*nylghau*), *B. tragocamelus*,
Leptobos fraseri Rüt.,
Bos namadicus Falc.,
Cervus duvaucelli Cuv. (allied to the modern "barasingha"),
Sus namadicus Pilg.[22],
Hippopotamus palaeindicus Falc. & Cautl. (belonging to a sub-genus now only found in Africa),
Hippopotamus namadicus Falc. & Cautl. (probably from an earlier Siwalik ancestor),
Equus namadicus Falc. & Cautl. (from the Siwaliks),
Rhinoceros unicornis Linn. (a living species),
Elephas antiquus (namadicus) Falc. & Cautl. (probably identical with the European, *E. antiquus*),
Stegodon insignis Falc. & Cautl. (Siwalik species),
Stegodon ganesa Falc. & Cautl.

The age of the fauna appears to be Middle Pleistocene, and equivalent to that of the Boulder Conglomerate stage of the Siwalik. Several of the vertebrate species are closely related to forms in the Kendeng beds of Java (T. de Chardin). Pilgrim equates the Narbada older alluvium with the Trinil beds of Java.[23] One of the palæolithic implements found in the Narbada deposits is a chipped stone scraper or hatchet discovered *in situ* near the village of Bhutra, eight miles north of Gadawara; the material is Vindhyan quartzite, and the shape similar to that of some of the implements found in the lateritic deposits of southern India, and in the post-Pliocene formations of Europe. The mollusca include no species which is not identical with one living at present in the same area.[24] Remains of crocodiles,

[21] Pal. Ind., New Ser., Vol. 18, 49 (1932).
[22] Pal. Ind., New Ser., Vol. 8, No. 4, 64 (1926).
[23] The Trinil beds, which have yielded the celebrated *Pithecanthropus erectus* Dub., associated with *Stegodon*, *Hippopotamus* and a doubtful *Mastodon*, are referred to the Lower Pleistocene by Dr. van Es ("The Age of Pithecanthropus", (1931).
[24] G. E. Pilgrim. Rec. 32, 215 (1905).

which are abundant in the Siwalik rocks, are few and fragmentary in the Narbada alluvium, though one species is common in the Narbada river at the present day. The vertebrate bones are isolated and broken, some of them being even rolled; they have every appearance of being derived from completely disintegrated skeletons, and not from floating carcasses or portions of carcasses which have sunk without dismemberment to the bottom of lakes. The Chelonia and fresh-water mollusca are all forms which inhabit either rivers or shallow marshes in river valleys. The uniform appearance and want of stratification in the clays, as well as the frequent pebble beds therein, are all common characters of river deposits. The fact of the Narbada alluvial formation between Nimawar and Jubbulpore occurring in a distinct rock basin—a matter to which we shall return when discussing the life-history of the Narbada, Tapti, Godavari and other Peninsular rivers—has led some to suppose that it was accumulated in a large lake. The existence of the rock basin, however, does not necessitate such an assumption, as we shall see, and the exposed Narbada beds have all the character of fluviatile deposits.

The Tapti and Purna valleys.—In the Tapti valley there is a large plain in Khandesh, extending east and west for about 150 miles and terminating eastwards close to Burhanpur. This plain lies chiefly to the north of the river and is probably in places as much as 30 miles wide. To the southeast it appears to be connected by a narrow belt of alluvium some 20 miles long—possibly a more recent deposit[25]—with the old alluvial plain of the Purna,[26] a tributary of the Tapti draining a large portion of Berar. The Purna plain is at a higher level than Khandesh and is about 100 miles long and in places 40 miles broad, its eastern extremity being near Amraoti. The whole length of the combined Tapti and Purna plains, therefore, is about 240 miles.

In the Purna plain the general fall in the surface is 170 feet in 78 miles,[27] *i.e.*, at the rate of 436 feet in 200 miles, a somewhat steeper slope than that of the Narbada alluvium. From Malkapur close to the western extremity of the Purna alluvial plain to Bhusawal just south of the alluvial flat near the eastern end of Khandesh (the Tapti alluvial tract) there is a drop of 139 feet in 30 miles, which is equivalent to a rate of 926 feet in 200 miles, a declivity more than twice as steep as that in the Purna plain.

In their principal characters the alluvial plains of the Tapti valley resemble the Narbada plain, but no deep borings have been made and the depth of the deposits is not known.[28] As in the Narbada valley, the Tapti river now flows at a considerable depth below the alluvial plain and is evidently cutting its channel deeper. The basin holding

[25] Man. 2nd Edit., p. 396, footnote (1893); see also E. Vredenburg, Rec. 33, p. 37, footnote (1906).

[26] Not the tributary of the same name which enters Godavari further south.

[27] Between Malkapur and Akola, a distance of 54 miles, and between Akola and Murtazapur, a distance of 24 miles: the heights above sea-level of these three stations, which are none of them out in the alluvium but close to its southern edge, are respectively 816 feet, 917 feet and 986 feet.

[28] Mem. 6, 276, 286 (1869); Rec. 2, 1 (1867).

the deposits under consideration is composed of the Deccan Trap, and it is through this lower part of the formation that the river cuts its way out to the west. No vertebrate remains have hitherto been detected in this alluvium but a systematic search would probably be more successful; as in the Narbada plain, the few mollusca found belong to fresh-water species inhabiting rivers. The gradient of the Tapti will be referred to later on.

The only peculiarity of the Purna alluvial deposits deserving of notice is the occurrence of salt in some of the beds at a little depth below the surface. Throughout an area more than 30 miles in length, extending from Dahihanda (Dhyanda), north of Akola, to within a few miles of Amraoti, *i.e.*, in the eastern third of the outcrop, wells are sunk for the purpose of obtaining brine in several places on both sides of the Purna river. The deepest wells are about 120 feet deep. They traverse clay, sand and gravel, and finally, it is said, a band of gravelly clay from which the brine is obtained. No fossils have been found in the clay and sand, dug from the wells. The occurrence of salt in the alluvial deposits of India is not uncommon, and it is impossible to say, without further evidence, whether in the present instance it indicates the existence of marine beds below. We know that a small marine gulf extended up the Narbada valley in Cretaceous times, and it is not impossible that a branch thereof may have covered the Purna area and left behind some saline relics; the present height of this part of the plain above sea-level is about 1,000 feet.

The Godavari valley.—The Godavari has but a slight general fall and forms abroad alluvial plain where it traverses comparatively soft beds; through harder rocks it cuts a steeper slope, though there is an exception to this in the gorge above Rajahmundry. Alluvial basins are not so distinct as they are in the cases of the westward flowing Narbada and Tapti, but extensive alluvial areas occur along the upper part of the river in the Bombay Presidency and the adjoining portion of the Nizam's dominions, and similar tracts are found on the Penganga, Wardha and Wainganga, tributaries of the Godavari in Berar, Nagpur and Chanda. The best defined of all these basins is one stretching from Nasik in Bombay E.S.E.' wards to beyond Paitan; it is over 120 miles long and is of the same general width as the Tapti and Purna outcrops.[29]

The composition of these deposits differs in no important particular from that of the Narbada and Tapti alluvium. The gravels are composed chiefly of rolled agates and fragments of basalt derived from the Deccan Traps which are the prevailing rocks in the upper part of the valley. Silicified wood from small fragments up to trunks 10 and 15 feet long is abundant along the western margin of the outcrop of the Chikiala sandstones in the valley of the Pranhita or Wardha from where that river crosses these Upper Gondwana sandstones twenty miles north of Sironcha town to the lower end of

[29] It should have been shown on the 32 miles geological map, from which it has been omitted.

PLEISTOCENE FOSSIL

Elephas antiquus (namadicus), Cranium (X1/13)

G. S. I., Calcutta

the "Second Barrier" of the Godavari, 28 miles southeast of the same town; below this point on to Albaka fossil wood is less abundant.[30] The greater portion of the alluvium in all cases consists of brown clay with *kankar*. In the Wardha valley, beneath the clay and calcareous conglomerates some fine light brown to grey sandy silt occurs west of Chanda, and contains salt of which a considerable proportion is magnesium sulphate.[31]

Vertebrate bones are to be found, sometimes (it is said) in large numbers, in the Godavari valley. One of the species identified is the gigantic *Elephas antiquus* (*namadicus*) Falc. & Cautl., apparently a heat-loving form. The tusk of the specimen described by Pilgrim measured 25 inches in circumference at its proximal end, but an older specimen which appears to have been lost is said to have attained 29 inches; the animal itself cannot have stood much less than 16 feet at the shoulder.[32] The lower jaw of a *Hippopotamus* has been assigned to *H.* (*Tetraprotodon*) *palaeindicus* Falc. & Cautl., and a single tooth has been identified as that of *Equus namadicus* Falc. & Cautl. Bones of *Bos* and other animals are also recorded. Crocodile teeth have been found and several molluscan shells identical with species existing in the area at the present day. All these specimens come from the large exposure between Nasik and Paitan. From the gravels near Mungi and Paitan, on the road from Ahmednagar to Jalna, an agate flake apparently of human manufacture was collected by Wynne,[33] another trace of man in the Pleistocene river gravels of the Peninsula.

The Penganga valley.—In the Penganga the Pleistocene gravels, though widely scattered, are not continuous; in some cases they form the bed of the river, but elsewhere the Penganga has cut down into the Deccan Trap or the older crystalline rocks below.[34] Near Hingoli in this valley bones are reported to have been found in immense quantities, but they have not been preserved and a later search resulted in a few bovine bones and failed to substantiate the existence of any extensive fossil remains.[35]

The Kistna valley.—The valley of the Kistna resembles that of the Godavari in many respects. There are similar plains of alluvial clay with beds of sand, gravel and calcareous conglomerate, but none of these plains appears to be of great extent. Beds of gravel have been observed in many places at a height of from 60 to 80 feet above the present level of the river and its tributaries.[36]

The only important mammalian remains hitherto found in the alluvial deposits of the Kistna and its tributaries consist of portions of the cranium and mandible of a rhinoceros and some bovine teeth

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[30] W. King, Mem. 18, 298 (1881).
[31] W. H. Huges. Mem. 13, 92 (1877).
[32] Rec. 32, 203 (1905).
[33] Rec. 1, 65 (1868).
[34] G. E. Pilgrim, Rec. 32, 200 (1905).
[35] W. T. Blanford, Mem. 6, 232 (1869).
[36] R. B. Foote, Mem. 12, 237 (1876).

and jaws, found on the Ghatpraba near the town of Gokak.[37] The bovine remains have not been determined, but the rhinoceros has been described under the name of *Rhinoceros deccanensis* Foote; it belongs to a species differing widely from all living forms, and does not appear to be very nearly connected with any known Indian fossil species. With the bones were found some fresh-water shells belonging to living species. Probably from some part of the upper drainage area of the Kistna, Colonel Sykes obtained the teeth of the trilophodont *Mastodon* described by Falconer under the name of *M. pandionis*. Large numbers of chipped quartzite implements of human manufacture, belonging to the same type as that discovered in the Narbada alluvium, have been found in various gravels in the southern Maratha country on the Malprabha and other affluents of the Kistna.[38] The relations between the ossiferous gravels and those containing the implements are, however, somewhat obscure.

Diamond gravels.—Nothing of importance is known concerning the older alluvial deposits of the remaining rivers in the Indian peninsula. It is in the Mahanadi, Kistna and Penner valleys that the principal diamond gravels are found, frequently at heights considerably above the present stream level; the pebbles in the gravels are composed of various kinds of Archæan rocks. The Koh-i-nur, according to tradition, was found somewhere near the Kistna river, and the Regent or Pitt diamond is said to have come from the Kistna district; whether either came from the Pleistocene river deposits, or whether both were obtained directly from the Banganapalle stage of the Kurnool series, which was probably in any case their original habitat, will never be known.[39]

Origin of the river plains.—There is still much obscurity regarding the origin of these old alluvial plains, of which the four tracts in the Narbada, Tapti, Purna and Godavari are the best examples. In the first place there is very little information concerning the precise shape of the rock basins they occupy. In the case of the Narbada, the Sukakheri boring, not far from the southern edge of the alluvium, reached a depth of 491 feet without attaining the base of the deposits, while another borehole close to Gadarwara railway station, a little further north, ended at 251 feet in the alluvial beds. The river itself, which is some 16 miles north of the deep Sukakheri boring, cuts through the alluvial clays, sands and gravels to the underlying rock, usually a member of the Vindhyan or Dharwar formations, and the section of old alluvial deposits on its banks never greatly exceeds 100 feet in depth. In other words the thickness of the alluvium has diminished to about 100 feet in the immediate neighbourhood of the river. The impression produced is that of a deposit banked up against a steep cliff to the south, formed probably by a fault, and thinning out northwards. This suggestion of a fault is confirmed by the straightness of the southern boundary of the alluvium in contrast to the winding and involute outline of its northern limit. The

[37] R. B. Foote, Mem. 12, 232-233 (1876).
[38] R. B. Foote, Mem. 12, 241-242 (1876).
[39] L. L. Fermor, Rec. 70, 97 (1935).

Narbada basin is reminiscent of some of the Gondwana basins which, as already noted, have been affected by faults. Followed westwards the southern and apparently faulted margin of the Narbada alluvium is seen to be in a line with the Narbada channel itself which maintains an unusually straight and direct course to its debouchment into the Gulf of Cambay; from Barwai westwards for nearly 100 miles the course of the river is almost a straight line. The conclusion seems justifiable that the Narbada occupies a large rift valley extending from the Gulf of Cambay to the vicinity of Jubbulpore. If, as seems probable, the formation of the rift took place at the end of the Deccan Trap period, before the tensile stress affecting the Peninsula during that time was replaced by the compression of the Himalayan movement, it must have preceded the deposition of the Narbada alluvium.

Bearing in mind all the facts known, we may now seek some explanation of the anomalous reversal of slope in the old bed of the Narbada. The present bed at the point where it leaves the alluvial plain near Nimawar and commences its course along a rocky channel traversing a 60 miles belt of gneiss, Bijawar and Vindhyan rocks, is not more than 200 feet lower than the surface of the plain at Gadárwara and Sukakheri. At this point of exit the Narbada valley is surrounded on all sides by higher rocky ground. In other words the point where the river leaves the plain, while representing the lowest level of erosion ever attained by the river at this part of its course, is now about 29 feet higher than the base of the alluvium, *i.e.*, the old river bed—120 miles further up-stream. The old bed of the river must, therefore, now show a slope upwards from Sukakheri to Nimawar. One of the earliest explanations of this anomaly was that the Indian peninsula suffered a tilt after the accumulation of the Narbada alluvium, the western side rising and the eastern falling. The present surface-slope of the alluvium shows no evidence of such a tilt. This surface, though undulating and evidently denuded by rain and streams, exhibits a slight but definite general declination westwards, *i.e.*, in the direction of the flow of the river. The fall along the surface in 200 miles has been estimated to be about 300 feet.[40] The supposed tilt of the Peninsula, to produce the effect for which its occurrence is hypothesised, would have been enough not only to compensate this slope but to reverse it to a noticeable degree, unless the deposition of river silt proceeded *pari passu* with the tilting movement.

An alternative hypothesis, propounded by Vredenburg, supposes that, instead of a wholesale tilt, the Peninsula was affected by an anticlinal warp, with a N.N.E.-S.S.W. axis stretching from a point west of Nimawar, through the narrow strip of alluvium joining the Purna and Tapti plains, to a point east of Paitan.[41] From the Deccan Trap period onwards most compressional earth movements acted from north to south producing E.-W. features. That there were at times

[40] The following heights above sea-level illustrate this: Harda Railway Station, near Nimawar, 947 feet; Sohagpur, 1,103 feet; Narsinghpur 1,185 feet; Jubbulpore, a little below 1,350 feet.

[41] Rec. 33, pt. 1, pp. 33-45 (1906).

stresses along an E.-W. direction, however, is seen in the presence of the great fault which is supposed to have been responsible for the formation of the west coast, and in the tilt which, as will be seen, affected Bombay in post-Tertiary times. Although an anticlinal warp in the direction postulated would explain the limits of the upper Godavari alluvial tract—if any explanation is considered necessary—and would fit in with the supposition that the Narbada at one time flowed into the Tapti across Nimar, the facts seem more simply and accumulatively in favour of a local vertical displacement along part of a rift, as the cause of the presence and disposition of these river deposits.

According to this theory, while the fissure which gave origin to the river was in its western portion a rift without any appreciable relative movement of its two sides, its eastern portion took on the character of a true fault or system of faults with a downthrow to the north.[42] We have already seen evidence for this in the thinning out northwards of the alluvium and in the way it is banked up against the southern wall of trap and underlying Gondwana rocks. The theory also offers a simple explanation of the reversal of slope in the old rocky bed of the Narbada. At times a temporary lake might have been produced, for lacustrine sediments may underlie the beds which have been exposed and show fluviatile characters; it is, however, not necessary to assume that a lake was ever formed, for the deposition of silt might easily have kept pace with the faulting, if the latter were the slow process as it usually is.

In the case of the Purna-Tapti, there is also direct suggestion of faulting or rift-formation, and there is no evidence against the supposition that some form of fissuring assisted in the formation of the greater part of this valley. Ignoring the small meanderings in the alluvium itself, the general course of the Purna-Tapti from below Kolhapur in the east to Chichli in the west is straighter than that of rivers south of the Trap area, such as the Kistna and most of its tributaries or the Cauvery; a line through the Purna-Tapti alluvium would, if produced, meet the Narbada fissure at the mouth of the latter river. Here again, if the alluvial plains are to be regarded as formed with the assistance of vertical relative movement, the faulting in these plains would appear to merge westwards into a rift with no appreciable dislocation. The straight wall-like escarpment of the Malwa plateau along the north side of the Narbada, and of the Deccan plateau south of the Tapti-Purna valley in southern Khandesh, are intrinsically suggestive of faulting and fissuring.

One argument in favour of the theory that the formation of the Narbada river valley—if not the accumulation of the Older Alluvium therein—was the result of fissuring or faulting, is the difficulty in understanding how the narrow Cretaceous gulf which appears to have been replaced by the river could have penetrated so far into the heart of the old continent, probably across the central back-bone range, in any other way than by the aid of such fracturing. A late

[42] Gen. Rep. Rec. 63, 112 (1930).

and local movement along a portion of this old fracture line, and another along the Purna-Tapti, it is suggested, may have caused the anomalies under consideration. It is impossible not to associate the extraordinary straight course of the major portion of the Narbada with faulting or rifting.

In tracing the geographical history of the Peninsula, it will have been seen that before the Deccan Trap outbursts, the main watershed must still have been the Aravalli range and its south-westward continuation over what is now the Arabian Sea. From this it is easy to understand the peculiar position of the present watershed of the Peninsula if we except the drainage of the Narbada and Tapti. This watershed, instead of occurring along the central parts of the land-mass, lies but a few miles east of and parallel to the west coast. All the large Peninsular rivers and their uppermost tributaries, with the exception of the Narbada and Tapti, rise on the eastern slope of the Western Ghats, the majority of them within 30 miles of the sea, and traverse practically the whole width of the Peninsula to empty themselves into the Bay of Bengal. The drainage into the Arabian Sea, again excepting that of the Tapti and Narbada, consists only of short petty streams. This anomaly is emphasised by the excessive rainfall of over 360 inches a year on the crest of the Western Ghats; in spite of this the westerly drainage is represented by insignificant streams which had to commence presumably on a vertical sea cliff with an initial catchment area not much above zero and in competition with a competent and well established easterly drainage.

The outbursts of trap would no doubt have affected the detail of the drainage lines here and there, but it is improbable that it had any effect upon the general trend of the rivers; the general directions today of the Godavari and Kistna, two rivers whose catchment areas lie largely within the immense outcrop of the Deccan Trap, support this contention. The highest belt of country in the pre-Trap Peninsular area remained and still is the highest belt, namely the Western Ghats, and it is difficult to comprehend how any outpouring of trap could have given rise to two such large westerly-flowing rivers as the Narbada and Tapti. The present anomalous easterly flow of so many of the main Peninsular rivers is, therefore, a relic of the pre-Trap drainage.

In the case of the Godavari the course is more winding, but even here the upper portion of the river, traversing the Trap, has a more direct course than rivers outside the Trap area; if a straight line be drawn from a point a few miles north of Nasik to Gangakher in Hyderabad, a distance well over 100 miles, the Godavari river is never more than 7 miles distant therefrom. Nevertheless there is no direct evidence of fissuring or faulting in the valley of the Godavari any more than there is in that of the Purna-Tapti; whether the accumulation of Older Alluvium in the Upper Godavari was assisted by a fault or not is a question which cannot be profitably considered until more is known of the depth of the deposits and the shape of the rock-basin they occupy. There can be no doubt that the Older Alluvium

of the Narbada, Purna-Tapti, Godavari and perhaps the Kistna and other rivers, includes Pleistocene sediments of the same age.

East Coast Alluvium.—Throughout the east coast of the Peninsula, from the delta of the Ganges to the neighbourhood of Cape Comorin, with the exception of a few miles near Vizagapatam, there is a belt of alluvial deposits varying greatly in breadth but nowhere exceeding fifty miles. In places the hills approach the sea, leaving only a comparatively narrow margin of sandy foreshore such as that seen to the south of the Chilka lake in Orissa and again near Pondicherry. Near the mouths of the great rivers Mahanadi, Godavari, Kistna and Cauvery, broad alluvial plains extend inland for many miles, and there is at the same time actually a projection beyond the general coast-line due to the quantity of river sediment deposited, although the strong currents which sweep up the coast prevent any great seaward extension of the deltas. It is these currents which are responsible for the fact that out of the six great rivers which empty themselves on the Coromandel coast, the Godavari, Kistna, Cauvery, Penner, Ponnaiyar and Palar, only the first three, which are the largest, have extensive deltas. To the action of these currents is also due the formation of sand-bars, cutting off lagoons or lakes of brackish water such as the Pulicat, north of Madras, the Colair north of Masulipatam, and the Chilka west of Puri, all of them extensive but very shallow sheets of water which is never permanently fresh. There is a tendency for the distal end of these river-bars to point towards the northeast or north. This is not invariably the case, the best example being that of the Chilka Lake near the head of the Bay of Bengal. It is a result of the prevalence of south and southeast winds in the Bay and of the heavy breakers produced by them along this coast, by the agency of which the sand and pebbles of the shore tend to travel northwards or north-eastwards. That this is happening near the Chilka Lake is proved by the abundance of pebbles of gneiss, granite, conglomerate, sandstone and even of fossils, on the shore near Puri, a little east of the lake; these pebbles must have been derived from rocks washed by the sea, and the nearest place where such rocks occur along the shore is the Vizagapatam coast over 150 miles away to the southwest.[43]

The Pulicat lake, imperfectly shut off from the sea by two long islands and dotted with smaller ones, has one small stream flowing into it. The two island bars have been formed by the deposition of silt brought down by the Palar river which now debouches into the Bay of Bengal 65 miles south of Madras but whose channel at one time lay to the north of that city just to the south of the Pulicat lake, as a geological map showing the distribution of the Palar alluvium clearly indicates.[44]

The Colair lake, now some 18 miles distant from the sea, is obviously just a shallow basin left between the gradually growing deltas of the Kistna and Godavari—a basin which has not yet been

[43] W. T. Blanford, Mem. 1, 252 (1859).
[44] W. King, Mem. 16, 122 (1880).

filled up by the silt brought down by the small Tammiler river draining into it. The lake is in tidal communication with the sea by a stream which, as the dry season progresses, becomes closed; when the Tammiler is in flood, there is a current outwards from the lake to the sea along the outlet stream.[45] The delta waters of the Godavari are distributed by a magnificent system of navigation and irrigation canals over the great alluvial plain; this canal system joins another on the Kistna delta, and the latter is connected with a coastal canal from Madras.

The Chilka lake represents a part of the sea, first rendered shallow by deposition from one of the mouths of the Mahanadi, and then cut off by a long spit with a very straight outward edge and incomplete at its northeasterly end.[46] The water in the lake, which is gradually but slowly decreasing in size, is never quite fresh. Deposits of subfossil shells are seen along the shores of the lake and are found in some quantity near the southwestern end of the spit, twenty or thirty feet above the present flood-level of the Chilka. These shells, as determined by Annandale[47] comprise the following:

Meretrix casta (Chemn.),
Sunetta scripta (L.),
Arca (*Anadara*) *granosa* L.,
Potamides (*Tympanotomus*) *cingulatus* (Gmel.),
Cuma disjuncta Annand.

The last three forms still survive in the lake, though the *Arca* has been modified. The *Sunetta*, though not found in the lake, is common on the sandy coast of Orissa, while *Meretrix casta* belongs to an extinct race, shells of which are common in comparatively recent brackish-water deposits on the east coast. Accompanying the above species are bleached shells of fresh-water species, probably younger than the brackish-water forms and all of them found living in neighbouring rice fields and village ponds. The lake, which is walled in by hills to the northwest, is 44 miles long and from 5 to 20 miles wide; it seems to have increased in size since it was the subject of observation by Blandford and Theobald in 1857-1858.[48] The lake bed is in some places slightly below low-water level, and most of it lies a very few feet below high-water level. During the dry months the lake is kept salty by the small tidal stream which rushes in from the sea between the narrow necks of sand; in the monsoon the salt water is driven out by river water and the lake becomes fresh.

To the northward the east coast alluvium joins the Older Alluvial deposits on the western side of the Ganges delta, the two resembling each other closely in mineral character. The coast alluvium consists chiefly of clays with *kankar* and, near the hills, pisolitic nodules of ferric oxide which in places is sufficiently abundant to render the deposit a kind of laterite gravel. Gravels and sand also occur,

[45] W. King, Mem. 16, 203-204 (1880).
[46] W. T. Blanford, Rec. 5, 61 (1872).
[47] Mem. As. Soc. Beng. Vol. 7, No. 4, 257-287 (1922).
[48] W. T. Blanford, Mem. 1, 251 (1859).

frequently more or less mixed with ferruginous concretions, and in many localities there is an apparent passage between the ferruginous gravel of the alluvium and the low-level form of laterite; in other places, however, the latter with its palæolithic implements is overlain unconformably by this Older Alluvium. The surface of the coast alluvium is usually quite flat near the sea and in the river deltas, but towards the hills it is more uneven and has undergone a considerable amount of denudation.

The sands along the shores from Cuttack through Ganjam and Vizagapatam to Tinnevelly, as well as those along the Travancore coast on the west side of the Peninsula, have undergone a process of natural elutriation, resulting in a concentration of heavy minerals such as ilmenite, monazite, zircon and garnet. In Cuttack, for example, such natural concentrations of black sand are found over a width of some 50 feet but attain a thickness of less than a foot. The average monazite content here is not more than 2.5 per cent., though small local deposits contain from 8 to 12 per cent.[49] In Ganjam the average monazite content of the richest sands is only about 5 per cent. These supplies of monazite and ilmenite, especially those of Travancore, have been made use of economically in the past and are still being erratically exploited. Zircon crystals also form a constant constituent of the beach sands of Travancore.[50]

The thickness of the alluvium has been tested at Madras by numerous recent borings which pierced it at about 75 feet from the surface and struck the crystalline rocks. Further south, at Pondicherry, it is much greater, one boring having been sunk 550 feet without reaching the base of the deposits; the alluvial deposits of Pondicherry are important in that they yield a supply of artesian water at various depths below the surface.[51]

Evidence of Recent Movement along the east coast.—While in some parts of the east coast there is evidence of post-Tertiary upheaval, in others there are signs of depression. There is reason to believe, as we shall see, that the great delta of the Ganges, as is usual with deltaic areas, has undergone and is still undergoing subsidence. A hundred miles southwest of Calcutta, on the other hand, evidence of upheaval begins and continues for nearly 200 miles along the Orissa sea-border. Behind Balasore, which is traditionally an old seaport but is now nine or ten miles from the sea, is an escarpment having every appearance of an old sea cliff. Clusters of isolated hills, evidently once islands, dot the countryside. Within the memory of man the tide came further up the rivers than it does now, and the export salt *golahs* (store-houses) had to be moved farther down the Brahmani. The Black Pagoda, now two miles inland, is said to have been built on the shore; it stands upon the inner of two rows of sand-hills which, there can be little doubt, mark successive seacoasts. Similar tracts of sand derived from a seashore and blown up to ridges by the wind, extend up into the Midnapore district of Bengal. All

[49] Gen. Rep. 58, 30 (1925).
[50] C. S. Fox, Trans. Min. Geol. Inst. Ind., 20, 258 (1926).
[51] W. King, Rec. 13, 113-138, 194-197 (1880).

this evidence merely proves a retirement of the sea and not necessarily an elevation of the shore. The latter is placed beyond a doubt, however, by the deposits in the Chilka and other lakes. It is borne out to some extent also by the unbroken nature of the sloping surface of the Cuddalore beds as they pass eastwards with their capping of laterite beneath the alluvium of the coast or terminate in a small cliff; such a slope, unaffected by subaerial erosion, is typical of sea action, and the low-level laterite caps must have been deposited either before or immediately after the slope was raised above sea-level.[52]

Along other portions of this coast the presence of coral reefs and marine deposits raised above the present level of the sea testifies to sub-Recent elevation. At Madras and Pondicherry shells belonging to recent species have been found from 5 to 20 feet beneath the surface, *i.e.*, considerably above present sea-level. Further south also, near Porto Novo in the lower part of the Vellar valley, a bed of estuarine shells is to be seen above the present flood-level of the river, and consequently at a considerable height above the sea.[53] Similar deposits of shells have also been noticed near Cuddalore, Tanjore, and Valimukkam in Tinnevelly.[54] These shells, as a rule, are estuarine forms such as now live in the creeks and backwaters of the coast, but in several cases true marine species have been found. The sub-fossil shells near Madras are so abundant in places that they have been collected for lime-burning. On the north of Rameswaram, an island off the coast of Madura, an old coral reef has been raised several feet above sea-level.[55] The gentle slope of older rocks on which lies the low-level laterite of the east coast is one such as is formed by the sea, unaffected by subaerial erosion, and the lateritic material must have been deposited either before or shortly after this plane was raised above sea-level.

The Cuddalore shelf of the east coast is repeatedly interrupted by the broad alluvial valleys of rivers, and for nearly a hundred miles south of Madras appears to be missing altogether. In this section of the coast evidence of elevation is confined to the raised shell-banks mentioned above in the neighbourhood of Madras and Pondicherry.

Evidence of recent subsidence, however, is not wanting and is unmistakable at Pondicherry and Valimukkam, where, in both cases, as we have just seen there are indications also of upheaval. In a boring at Bahur in Pondicherry, for instance, a bed of lignite 35 feet thick was struck at a depth of 240 feet; it is too impure to be of commercial importance but is interesting as evidence of a subsidence corresponding to the depth at which it was found. The subsidence thus indicated must evidently have preceded the upheaval which elevated the shell banks, and have amounted to 240 feet *plus* the present height of the shell banks above high-water mark. Evidence of subsidence to a less degree and of a later date is found also at the

[52] H. F. Blanford, Mem. 4, 165 (1863); Ibid., 256 (1864); Ibid. 10, 59 (1873); and R. B. Foote, Ibid., 20, 35 (1883).
[53] Mem. 4, 192 (1863).
[54] Mem. 4, 254 (1864).
[55] R. B. Foote, Mem. 20, 70 (1883).

western end of Valimukkam Bay in the Tinnevelly district, where a submerged forest, covering about half an acre, lies at or just below high-water mark; the tree stumps have diameter of 1 to 1½ feet at the base, and are immersed in black mud containing the remains of detached twigs and branches. An incised bone pendent, apparently washed out of this mud, would show that the forest flourished since the advent of man. The trees of this forest can hardly have grown at sea-level or on the coast so that there must have been some subsidence. This subsidence preceded the elevation of Valimukkam which is mentioned above and which is proved by the occurrence close by of *Potamides* and other littoral marine shells in clay above high-water level.[56] Near Pondicherry and, as we shall see, in the alluvium of the Gangetic delta, beds of peat at various levels below the surface also witness to subsidence but this is the usual if not invariable condition in a delta, and it is more than probable that all the large deltas along the coast are being slowly depressed.

Some extensive accumulations of quartzite shingle round the bases of some of the hills of North Arcot suggest raised beaches and, if correctly so, record an early phase of upward movement. These deposits are considered to be more or less contemporaneous with the laterite formation in which Palaeolithic chipped implements have been found.[57] If rightly diagnosed as marine shingle, these deposits, in some cases over 50 miles from the present sea coast, indicate a considerable retreat of the sea due to upheaval, in the neighbourhood of Madras since the advent of man.

Besides the changes produced by rise and fall of the sea-level as compared with that of the land, there have been minor modifications of the shore line which appear to be due entirely or almost entirely to erosion or accretion of land. St. Thome, a short distance inland, while 40 miles farther south the town of Mahabalipur is said to have been overwhelmed by the sea. Still farther south, erosion of the beach at Tranquebar is well attested by old records, as well as the destruction of an old pagoda, whose eastern gate tower had been partially destroyed in 1859.[58]

Evidence of the advance of land is to be found on the Tinnevelly coast, where the deserted town of Korkai, now five miles inland, has been identified with the "Kolkoi Emporium" of the classical geographers. About 600 B.C. this town was the capital of a kingdom and apparently an important seaport, celebrated for its pearl fisheries in A.D. 80. By the time that Marco Polo visited this coast in 1292 A.D., the advance of the land had necessitated the abandonment of the old port and the establishment of a new one at "Cail", a town which also has decayed and was forgotten till its site was discovered and recognised by Bishop Caldwell in the modern village of Kayal, and made public in Colonel Yule's edition of the travels of Marco Polo.[59]

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[56] Mem. 20, 83 (1883).
[57] R. B. Foote, Rec. 12, 205 (1879).
[58] H. F. Blanford, Mem. 4, 362 (1864).
[59] First Edit., Vol. 2, 307 (1871).

The smooth-water anchorages off Cochin and Travancore.—Off the coast of Cochin and Travancore are the remarkable smooth-water anchorages of Narakal and Aleppey (Aleppi). These are mud banks of about four miles in length, whose position varies in the course of years within the extreme limits of about eleven miles, and over which smooth water can always be found, however tempestuous the sea outside may be and in spite of the fact that they are open to the full force of the southwest monsoon. It was this peculiarity which first attracted attention and rendered them important to the navigators of a coast along which there are no sheltered harbours.[60]

According to the most recent investigation of the subject, these anchorages owe their origin to a bed of very soft, fine-grained, greenish clay containing foraminifera and diatoms, and underlying the soft recent sandstones which are exposed along the surface of the narrow bars of land separating the sea from the backwaters of Travancore and Cochin. When the water-level in these backwaters is raised by the monsoon rains, this mud is forced outwards and rises in cones and ridges under the sea as well as along the shore; the effect of its thorough admixture with the sea-water is to abate the waves of the sea outside and produce comparative calm over the mud banks.

The mud was originally reported to contain an appreciable amount of oily matter which, it was suggested, might have contributed to the pacification of the waves. An analysis by R. G. Neilson, however,[61] showed that this can not be the case. The dried mud yielded only from 0.84 to 2.25 per cent. of bituminous or organic matter soluble in ether, and on destructive distillation gave from 0.45 to 0.83 per cent. of a nitrogenous, non-saponifiable oil. having the strong pungent odour characteristic of pyridine, quinoline and other substances resulting from the distillation of bones and similar nitrogenous animal remains. Such compounds are not ingredients of natural petroleum and Neilson concluded that the oil was probably derived from animal remains in the mud which under the microscope, is seen to contain carbonaceous matter and minute shells. There is no doubt, therefore, that in these smooth-water anchorages of Cochin and Travancore the sedative is the large quantity of impalpable mud which is held in suspension in the water and increases considerably its viscosity. The force of the waves is thus largely dissipated by the mutual friction between the mud particles. As the proportion of mud is much less at the surface than it is below, the lower part of any wave is retarded more than the upper; if the downward increase in viscosity be sufficiently rapid, the wave may actually break. if this increase is more gradual the wave merely loses its force and becomes more or less obliterated. The effect of this downward increase in viscosity is perhaps enhanced to a slight extent by an increase in density from above downwards, due to the torrents of rain falling on the sea as well as to the large amount of fresh water poured out by neighbouring rivers. In this

[60] W. King, Rec. 17, 14 (1885); P. Lake, *Ibid.*, 23, 41 (1890).
[61] Rec. 34, 40 (1906).

way fresh water floats on the surface of the sea in such quantities that ships may often replenish their stock by dipping over the side of the vessel with a bucket.

West Coast Alluvium.—As already mentioned, the sands along the coast of Travancore are richer in monazite than those along the east coast and compare with monazite-bearing sands of Ceylon. The percentage of thoria (ThO_2) present as a normal silicate in the monazite varies from about 6·8 to 10·2 ; locally rich sands yield as much as 60 per cent. of the mineral.[62]

The latter is washed out of its parent rock and is more or less naturally concentrated by its own weight amongst the sands of the seashore, where it is found in small round, amber-coloured grains from 0·1 to 0·2 mm. in diameter, with a density of 5·19 and a very high refractive index. Its collection and further concentration by mechanical means gave rise to a flourishing industry which, however, rapidly declined when electricity began to supplant gas-lighting, for which incandescent mantles had come to be used. India possesses by far the largest reserves of monazite known in the world and these, as regards thoria contents, are superior to any others.[63] The Travancore sands average about 10 per cent. of Zircon and 70 per cent. of ilmenite.[64] Some of the pegmatites of the neighbourhood are rich in monazite which occurs therein as a primary accessory ; the bulk of the material in the sands, nevertheless, is thought to have come from the denudation of charnockites and granulites, in which the mineral is known to occur in small quantities.[65] G. H. Tipper finds that monazite is most likely to occur where charnockites are well developed,[66] and the mineral has been identified by Iyer as an accessory in the charnockite of North Arcot,[67] and by Chacko in the charnockite of Travancore.[68] Sands from the adjoining coasts of Cochin, for instance, yield no trace of monazite. The mineral occurs widely in the Tinnevelly district, but has not been noticed in the sands of Ennore, near Madras. It is found at Waltair, at Bimlipatam in Vizagapatam, and at the entrance to the Chilka Lake, but not in the pegmatite districts of Nellore and of Bihar and Orissa. Incidentally it has been found sparingly in Idar State, north Bombay, but is absent from the sands of the Indus above Attock and from the concentrates of southern Burma sands.

Along the western shore of the Peninsula there is no such continuous plain of alluvial deposits as that found along the east coast. The ground between the Western Ghats and the sea, where not hilly, has a gentle general slope towards the sea, and is composed of rock, covered in many places by laterite. The line of the coast is rocky in parts, and alluvial deposits are confined chiefly to the vicinity of

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[62] Gen. Rep. Rec. 58, 30 (1925).
[63] Rec. 64, 255 (1930).
[64] C. S. Fox, Trans. Min. Geol. Inst., Ind., 20, 216 (1926).
[65] Gen. Rep. Rec. 42, 69 (1912).
[66] Rec. 44, 195 (1914).
[67] Gen. Rep. Rec. 66, 113 (1932).
[68] Ann. Rep. State Geol. Trav., 1903 p. 7.

the small streams which run from the Western Ghats to the sea, or of the backwaters or lagoons which have been cut off by banks of sand along the coast. In Travancore and Malabar the backwaters, like those of the east coast, are of considerable extent; farther north and along the coast of the Bombay Presidency they are wanting.

The alluvial valleys between the hills are unimportant to the south of the city of Bombay. Alluvial plains of comparatively recent formation connect the hills of Bombay island with those of Salsette, a few creeks alone remaining to show the position of former marine channels. Farther north these plains gradually increase in extent, until they merge into the alluvial flat of Gujarat. A boring at Sanand railway station reached a depth of 300 feet without encountering the base of this alluvium.[69] In Rajpipla the alluvium contains beds of trappean pebbles at various levels from the bottom to the top, and includes sandy beds hard enough to be called sandstone; calcareous concretions are generally abundant and tufaceous limestone is not uncommon.[70]

At Bombay the alluvial deposits consist of blue and of yellowish brown clay. The former varies in thickness from a few inches to several feet, its upper surface being at present one or two feet below high-water level. It is very salty, and contains small grains and nodules of *kankar,* and occasionally plates of gypsum. This blue clay is frequently penetrated by mangrove roots, which are usually riddled by *Teredo* borings just as are those in the mud of tidal creeks; at one spot large masses of oyster shells have been found in the clay. The yellowish brown clay appears to be the older of the two deposits. Its surface is frequently above sea-level, it abounds in larger masses of *kankar,* and it has occasionally yielded estuarine shells such as *Placuna* and *Ostraea.* That these alluvial deposits are estuarine and precisely similar to the mud now being deposited in the creeks and backwaters of the coast or on the shores of Bombay harbour, is shown by similarity of mineral character and by the organic remains, both vegetable and animal, found in this clay.

Indications of subsidence near Bombay.—Some interesting indications of subsidence were found in the excavation of the Prince's Dock on the east side of Bombay island in 1878. A large number of tree trunks were found in the blue clay, submerged to a depth of some 20 feet below mean sea-level, but in many cases retaining their upright position and with their roots attached to the soil in which they had grown.[71] Out of some 382 trees uncovered over an area of 30 acres, 223 consisted of erect stumps; one of the fallen logs measured 46 feet in length with a girth of 3 feet, but stumps reaching 4½ feet in girth were also noted. Samples of the trunks *in situ* were identified by J. S. Gamble as belonging to their *khair* (*Acacia catechu*), a well known Indian forest tree inhabiting the drier parts of the Peninsula both inland and near the coast but not growing below the level reached by the tides. Two samples from fallen and apparently drifted logs were recognised as teak. The scanty soil in which this

[69] T. H. D. La Touche, Rec. 40, 104 (1910).
[70] P. N. Bose, Rec. 37, 176 (1908).
[71] T. H. D. La Touche, Rec. 40, 104 (1910).

forest is rooted lies upon a very uneven surface of decomposed basalt or *moorum* forming the floor of Bombay harbour. This old soil is furrowed by wide shallow channels filled in with younger soil and masses of boulders. The stiff blue clay in which the tree stumps are imbedded varies in thickness from 6 to 20 feet, and on its almost horizontal upper surface lie 4-5 feet of harbour silt or dark brown mud. All the trees had been broken off at the level of the upper surface of the blue clay and were completely riddled to a short distance below this level with the borings of *Teredo* "which had evidently attacked the wood from above downwards, since the holes not only became larger as they approached the roots, but were entirely confined to the interior of the stumps."[72] One of the logs is reported to have shown signs of having been partially burnt, from which it is presumed that the forest was occupied by man before its submergence. During the excavations in 1910 connected with the extension of Alexandra Dock, four more tree stumps were uncovered, three of them in a standing position and having a height of 6-7 feet, corresponding with the thickness of the blue clay in which they were found imbedded. In the clay adhering to the roots of one of these trees were several oysters with valves united, identified as *Ostraea cucullata* Born., a species abundant in brackish water. The surface on which the trees were rooted is in the Alexandra Dock area sometimes as much as 40 feet below the level now reached by the highest tides, and this must therefore be regarded as the minimum amount of depression undergone by the old land surface.

The evidence of subsidence in these docks is unmistakable, but on the western side of the island there are equally valid signs of elevation in the form of an old beach, composed of shelly gravel partly consolidated into a littoral concrete, raised to a height of 12 feet above high-water mark. The sequence of events, as suggested by La Touche, seems to have been as follows: "The forest grew in a scanty covering of soil on a rocky coastal plain, traversed by wide and shallow watercourses and dotted with low hills, the crests of which now probably form the islands in the harbour. A gradual depression of the whole of the coastal area then set in, converting the creeks into backwaters or lagoons, and flooding the forest area with brackish water, so that oysters were enabled to attach themselves to the roots of the trees. Over the submerged area layers of fine clayey silt were deposited, supporting a growth of mangroves along the seaward face, but not in the less saline lagoons which lay behind. Further depression exposed the outer fringe of the deposits to the action of the waves, and masses of shingle and shells were laid down upon them, afterwards consolidated by the infiltration of carbonate of lime into the so called 'littoral concrete'. The character of the movement appears then to have changed, and to have taken the form of a tilt of the rock surface in an easterly direction, away from the open sea. The comparatively rapid submergence of the inner lagoon thus caused brought the sea in over the deposit of silt, in which many of the trees still remained standing. With the sea-water the *Teredo* was

[72] T. H. D. La Touche, Rec. 49, 215 (1918).

introduced, and attacked the bases of the trunks protruding from the silt, so weakening them that they were no longer able to withstand the action of the waves and wind, but were broken off and drifted away. At the same time the deposition of lagoon silt ceased entirely over the area invaded by the sea, and was succeeded by that of the ordinary harbour silt. The simultaneous rise of the seaward face of the island brought the shell gravels and the clays beneath them up to their present position above or near high-water mark, and converted the more low-lying parts of the island into lagoons and backwaters, in which the deposition of silt, resembling and in fact continuous with the beds which underlie the 'littoral concrete', proceeded until the low ground was artificially cut off from the sea."[73]

It is evident that Bombay harbour is the last remaining inlet out of many which formerly indented the Bombay coast, and that the tendency is for this harbour to become gradually and slowly silted up and converted into dry land. Except at Bombay, little has been recorded concerning the alluvium of the west coast south of Daman.

The plain of Gujarat.—In the neighbourhood of the rivers Tapti and Narbada there is a broad and fertile alluvial plain near the sea,[74] resembling in some of its features the alluvium of the east coast. Commencing to the southward near Daman, this plain covers the greater portion of the Surat, Broach and Ahmadabad districts, and continuous as far as the Rann of Cutch where it joins the area of recent deposits connected with the Indus valley. This great plain of Gujarat, with its regular rainfall and numerous rivers, has been styled the "garden of India"; its breadth is about 30 miles near Surat, and 60 miles near Baroda. The Alluvium of eastern Gujarat consists of brown clays with *kankar,* resting upon sands and sandy clays with occasional gravels. The surface is covered with black soil to the southward, though not in the district of Ahmadabad; it is frequently flat over considerable areas, but in parts of the country the ground has been rendered undulating by the action of rain. The deposits, though unfossiliferous, appear to be chiefly estuarine or marine, and have probably been raised, as on the east coast. The Gulf of Cambay is reported to be silting up gradually, and there can be little doubt that it was formerly part of a broad inlet leading from the Rann, then an inland sea, to the ocean, and that the remainder of the inlet has been converted into the alluvial plains of Ahmadabad, Broach, Surat and northeast Kathiawar.

The Rann of Cutch.—While this advance of the shore-line along the east coast of the Gulf of Cambay was taking place, the Rann of Cutch (Kachh), lying between Sind and the peninsula of Kathiawar became converted from a marine gulf to a debatable land which is flooded during the southwest monsoon and becomes a dry, barren, mud-flat during the rest of the year; this is the result of a silting up of the area aided by a slight elevation of the land.

The Rann is, in fact, an ancient inlet of the sea which for the most part has dried up. It is divided roughly into two by the large

[73] Rec. 49, 218-9 (1918).

[74] W. Blanford, Mem. 6, 232 (1869); A. W. Wynne, Rec. 1, 30 (1868); *Ibid.,* 8, 49 (1875).

island of Cutch and another smaller island; to the north lies the desiccated plain of the Great Rann, to the south lie a similar plain on the landward side—the Little Rann—and the Gulf of Cutch on the seaward side.

The Rann of Cutch consists of an immense marshy salt plain, scarcely above the sea-level and stretching for 200 miles from east to west, and in places nearly 100 miles from north to south. From the southeastern extremity a low alluvial tract, dividing Ahmadabad from Kathiawar and including an extensive brackish-water marsh called the Nal, connects the Rann with the head of the Gulf of Cambay. A trifling depression, probably not amounting to 50 feet, would convert Kathiawar into an island, and a still smaller subsidence would suffice to isolate Cutch completely. The Great Rann receives what little drainage the river Luni may bring down from time to time from the deserts and hills of Rajputana; the lower part of this river is salty. Into the Little Rann enters the Saraswati; rising now in the Aravallis, this river, though small, is of historical interest and is probably a remnant of the large holy river of that name which, there is reason to believe, once coincided with the upper Jumna and traversed Rajputana. The Great Rann covers some 10,000 square miles inclusive of the Banni, a low-lying tract scarcely distinguishable from the Rann except by some coarse vegetation which exists upon it.[75]

On the hard and polished surface of this salt-soaked plain of fine sand and clay the rain neither sinks nor runs off but rests in large shallow sheets which move along before any wind that may be blowing and grow to a more and more concentrated brine as evaporation proceeds, till only a bed of salt remains. The surface, covered with such a saline efflorescence, never pulverises even in the hottest weather but is usually so hard that a horse's hoof scarcely dents it in passing.[76] During the monsoon the Rann is liable to flooding not only by the rain but also by flood water from the streams draining there into. At this time portions of the Rann are seven feet under water, though the average depth does not exceed five feet. The inundation lasts from July to the end of November and portions of the surface, especially a tract to the westward near Sindri, depressed by the earthquake of 1819, are constantly covered with water. Below this water there is in places a bed of salt, sometimes as much as three feet in thickness.

There can be little doubt that the Rann was a gulf of the sea within recent times. Traditionally it once had sea ports on its shores, while anchors and the remains of sea-going ships are said to have been found imbedded in the mud.[77] Khor, a village in Kathiwar on the edge of the Little Rann is said to have been a seaport in 1765; Virawah on the Sind side of the Great Rann, now 120 miles

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[75] Mem. 9, 5 (1872).

[76] Sir Bartle Frere, Journ. Roy Geogr. Soc. 40, 185, (1870).

[77] Sir B. Frere states on apparently good traditional evidence that Virawah, in Nagar Parkar, northeast of the Rann, was a seaport from 500 to 800 years ago. Journ. Roy. Geol. Soc., 40, 195 (1876); no mention, however, of any sea north of Cutch appears to have been made by the Chinese travellers of the

from the Kori Creek, is also reported to have been a port. At one spot, resting upon local Jurassic rocks at a height of nearly 20 feet above the Rann and sloping towards it, is a small patch of sub-Recent littoral concrete full of marine shells. Furthermore, the present condition of the surface—an immense flat of sandy mud—can only be explained by supposing that the tract is the site of an inlet now silted up. Flooded by salt water during one season and exposed to hot dry weather at another, the soil becomes too salty to sustain even the mangrove vegetation of ordinary sea-water. The surface is being gradually raised by the silt brought in by rivers, however, and the few isolated tracts which do support vegetation must in time extend. In the plain itself there is no sign of animal or vegetable life to break the monotony, and the bones of a dead camel are visible for miles, whether seen in their actual shape and size or drawn up into some form of mirage.

Borings in the Little Rann have shown that layers of stiff bluish and black clay, totalling some 4-9 feet, overlie a brine bearing gritty sand. The clay contains some cerithiids and a *Cyrena*—probably *C. impressa* Desh. while in the sand, fragments of *Avicula, Corbula* and *Nassa* have been obtained. The indications are that estuarine succeeded marine conditions in Recent times.[78]

The recent history of the Rann of Cutch has been recorded in detail by R. D. Oldham.[79] In June 1819 a severe earthquake shock destroyed some hundreds of the inhabitants of Cutch, shook every fort in the country to its foundations, and caused an inundation of the sea which swept over about 200 square miles and overwhelmed the little fort of Sindri; the sheet of water thus formed is said to have been navigable by boats of some size. This disturbance was the result of a movement along a fault of considerable size, which built up a mound of earth or sand. The latter is said to have extended for some 60 miles; it become known as the Allah Band or *band* (mound) of God and is not to be confused with artificial dam erected previously on the Sind mainland further north, the Ali Bandar. The Allah Band, varying from 2 to 8 miles in width, has a gradual slope to the north, but a well defined limit to the south. The throw of the fault has been estimated at 30 feet, the upthrow side rising some 20 feet about the level of the lake formed by the inundation, and the downthrow some 10 feet below it. The western end of the *band* lies about 5 miles from Gari, but the dislocation is likely to have extended further west; from the point mentioned it runs with some irregularities in a general S.E.-by E. direction for 16

seventh century (Cunningham; " Ancient Geography of India ", I, 302). When Alexander the Great sailed down the Indus, he passed through the great eastern branch, then the main stream of the river, but now dry, to the Kori mouth; near the latter he came to a great lake (Anabasis, VI, 20). Mention is also made of a great lake-like expanse of water in this direction by some Mahomedan historians. (Mem. 9, 26 (1872); Trans. Geogr. Soc. Bomb., 18, 56, 69, 85 (1868)).

[78] Gen. Rep. Rec. 56, 33-34 (1924).

[79] Mem. 46 pt. 2, (1926).

miles to a point where it is breached by the Puran. Thence it bends round to an E.N.E. course for 7 miles, after which it again changes its direction to S.E. for about 15 miles. Throughout this length of 38 miles it marks the northern limit of the area which was flooded. Accompanying the earthquake were numerous and widespread landslips; sand vents were also frequently noted where conditions were favourable. After-shocks were numerous. A further depression is said to have taken place in 1845 in the same neighbourhood.[80] In 1869 the greater portion of the inundated area had been filled up nearly to the level of the Rann, a small shallow pool alone remaining around Sindri.

In the portion of the Gujarat plain which forms the neck of the Kathiawar peninsula, between the head of the Gulf of Cambay and the Little Rann there still exists a large shallow lake of brackish water, called the Nal, about twenty miles in length by three or four broad.[81] In the neighbourhood of this marsh cerithiid shells—probably *Potamides telescopium* or *P. fluviatilis*—are found, showing that estuarine conditions have prevailed at no distant period, and confirming the conclusion that the depression between the Kathiawar peninsula and the mainland is an old marine inlet silted up in the recent times. The distribution of the black soil in the neighbourhood of the Nal will be noticed presently.

Alluvium of Kathiawar and Cutch.—Along the south coast of Kathiawar there is very little alluvium, its place being taken by a calcareous grit which carries marine shells and is evidently of late formation. A glance at the map will show that this coast is exposed to the full action of the currents which sweep along it and prevent the accumulation of sediment. A patch of recent deposits has been mapped at the western extremity of the Kathiawar peninsula, but along its northwestern coast the Deccan Traps extend down to the seashore. The belt of alluvium reappears in Cutch, where it is from three to ten miles broad;[82] there is here only one place where rocks come down to the shore and this is in the Gulf of Cutch. The alluvial plain of Cutch consists of a brown loam resting upon mottled clay, with *kankar* and grains of quartz.

Littoral Concrete of Bombay and Kathiawar.—Allusion has already been made to the so-called 'littoral concrete' found along the western side of Bombay island, where it forms the flat ground of the Esplanade and part of the surfaces on which the Fort was built; the same deposit is also found at Mahim and other places in the island resting sometimes upon rock but more often on the blue alluvial clay described previously. It is also seen to the southward at Malwan[83] and northward here and there as far as Daman, where it has been observed apparently in process of formation.[84] A little raised above sea-level, this deposit is an agglutinated shelly grit, composed of shells, corals, pebbles and sand, cemented together more or less

[80] Capt. Nelson, Q. J. G. S., 2, 103 (1846).
[81] Mem. 21, 130 (1884); Alex. Rogers. Q. J. G. S., 26, 118 (1870).
[82] Mem. 9, 81 (1872).
[83] Mem. 12, 243 (1876).
[84] Rec. 1, 32 (1868).

thoroughly by carbonate of lime, and sufficiently compact in places to be employed as an inferior kind of building stone. Near Bulsar, a little north of Daman, the deposit is stratified and dips at a low angle towards the sea.

In western Kathiawar the littoral concrete is much more widely developed. Here it assumes the character of an earthy calcareous grit, is usually of a dark colour and ashy appearance, and contains marine shells and corals. Resting unconformably upon the denuded surface of the miliolite, it occasionally attains a thickness of 60 feet. The fossils found in this calcareous grit, so far as is known, are all species now living in the neighbouring coast.

There can be little doubt that these shelly calcareous grits of the Bombay and Kathiawar coast are of marine and not estuarine origin; they represent an accumulation of the sand and pebbles found on the shore together with marine shells and corals, and their position indicates a rise of the land, trifling at Bombay but greater in Kathiawar. The beds may have been originally sand-spits or beach deposits, very little, if at all, above high-water mark, and consolidated by the cementing action of carbonate of lime after being raised.

The Coasts of India.—The escarpment of the Western Ghats—a remarkable feature parallel to the west coast of the Peninsula—has frequently been evoked as evidence of a recent rise of land. Throughout the trap country of the Bombay Presidency the Ghats rise from the Konkan in a straight almost unbroken wall, varying in height from 2,000 to 4,000 feet, cut back in places by streams, projecting here and there into long promontories, but preserving throughout a singular resemblance to sea cliffs. The only noticeable indentation in this coast is Bombay harbour which, however, does not disturb the regularity of the actual sea face. The cliffs of trap are separated from the sea by a narrow belt of low-lying country of which the Bombay Konkan forms a typical part. This low fringe is not always covered by alluvium but is in places rocky. In the Konkan the rock is the Deccan Trap, of which also the overlying cliffs are composed. The resemblance of the Trap scarp to sea cliffs ceases to a great extent southwards, where metamorphic rocks replace the horizontal basaltic traps. The Western Ghat escarpment, however, is strongly reminiscent of the much smaller scarps of the Malwa plateau north of the Narbada and of the Deccan plateau south of the Tapti-Purna valley— scarps which there is some reason for regarding as marking the presence of rifts or faults. The parallelism of the Western Ghats escarpments to the sea-coast is suggestive of a connection between the two, and this suggestion is strengthened by the fact that the plane of marine denudation, already mentioned as supporting the low-level laterite, extends in places nearly to the foot of the scarp. The traps which, it seems almost certain, once stretched westwards over a large part of the Arabian Sea, may well have been submerged beneath the latter by a system of parallel faulting with downthrow to the west. Relics of this sunken portion of

India, with remnants of relief features still preserved, have in fact been recently located below the Arabian Sea by the John Murray Expedition.[85] The Ghats are inhabited by certain fresh-water mollusca belonging to the genus, *Cremnoconchus* (*Cr. syhadrensis* Blanf.),[86] which is unknown elsewhere and lives on vertical rocks kept wet by the spray of waterfalls ;[87] this mollusc is so closely allied to Indian forms of the littoral marine genus, *Litorina*, as to render it probable that both are descended from the same ancestors ; this relationship tends to strengthen the view that the Ghats were at one time actually washed by the sea. If so, it is certain that great denudation has taken place since the scarp was a sea-cliff, and that the latter was a feature of some epoch in the Tertiary period. If its formation were contemporaneous with that of the presumed Narbada and Tapti fissures, it probably took place soon after the beginning of the Tertiary period, and would thus have been very much earlier than the stupendous system of graben faulting which affected east Africa and western Asia at the beginning of the Quaternary era and was responsible for the formation of the Erythræan, Aden and Persian rift valleys ; during this younger disturbance long blocks of the earth's crust are supposed to have sunk between parallel faults, initiating such features as the Red Sea basin and its extension to the Jordan valley, the Gulf of Aden and the Persian Gulf, as well as the great rift valleys of east Africa.[88] Along the west coast of India, therefore, there appears to have been two phases of movement, first the early Tertiary faulting which produced the sea cliffs corresponding approximately with the present line of the Ghats, and secondly a uniform upheaval of the coast as a whole, perhaps at a comparatively recent date, with the formation of the narrow, regular, low-lying strip now known as the Konkan. It is possible that the isolation of the different plateau ranges of southern India, and the denudation of the Palghat Gap south of the Nilgiri plateau, are due in part to ancient marine invasion of the same date as the formation of the Ghat's scarp.

The formation of the west coast of the Indian peninsula dates from some epoch prior to the end of the Aquitanian ; this is indicated by the Gaj beds found in Travancore near Quilon.

No marine sediments older than these are known, if we except the Cretaceous beds of the lower Narbada valley which appear to have been laid down in a gulf of the western sea. At the close of the Deccan Trap period, previous to the Gaj epoch, dry land must

[85] The Expedition has demonstrated the presence of a longitudinal ridge down the Indian Ocean, corresponding to the similar ridge down the middle of the Atlantic. The specimens of basalt obtained from the former, which has been called the Carlsberg Ridge, differ strikingly from the Deccan Trap and in fact from plateau basalts in general, exhibiting a lower total iron content, a much lower percentage of ferrous oxide, less potash and more alumina (J. D. H. Wiseman. Geol. Mag., 74, 222 (1937).

[86] J. A. S. B. 49 (2), p. 221 (1880).

[87] N. Annandale, Rec. Ind. Mus., 19, pt. 2, No. 10, 46 (1920).

[88] A. W. Grabau, Bull. Geol. Soc. China, 6, 231 (1937).

have extended considerably west of the present line of the coast. South of the Trap area the evidence is only negative, but the absence of any large valleys draining westwards in the Peninsula suggests that the present position of the shore line is of more recent origin than that of the east coast; the easterly trend of most of the Peninsular drainage is probably of very ancient date.

The east coast originated much earlier and has maintained very much its present position since Lower Cretaceous (Upper Neocomian) times, as shown by its fringes of Cretaceous and Tertiary marine sediments.

The curious hilly Kathiawar peninsula interrupts the line of the Malabar coast towards the north, separating the Gulf and Rann of Cutch on the north from the Gulf of Cambay on the south, the latter receiving the waters of the Narbada, Tapti and smaller rivers. The regular curve of the Kathiawar coast and the lack of conspicuous indentation along the Makran coast is due largely to strong tides which sweep the head of the Arabian Sea. In contrast to the west coast of the Peninsula is the east or Coromandel coast with its marginal lakes and recently acquired alluvial fringes. The Bay of Bengal, during the end of the monsoon period, is subject to severe cyclonic storms which move up from the south or southwest and dissipate themselves inland after crossing the coast. During the monsoon curious booming noises known as the "Barisal Guns", are sometimes heard in Calcutta and the neighbouring country coming from the direction of the sea; they are caused probably by the great breakers beating upon the coast.[69]

Evidence of elevation and depression along the west coast.— Indications of earth movement along the west coast have been enumerated above. The presence of lignite in the Warkalli beds denotes an early period of depression. That this was followed by elevation is proved by the exposure of the deposits, the upper surface of which constitutes an old marine terrace, broken here and there into small isolated plateaux; parts of this terrace now lie some 180 to 200 feet above the sea, but the movement appears to have produced a tilt towards the north. In the island of Bombay we find evidence of upheaval along its western side and of subsidence along its eastern margin; the surface on which the buried trees are rooted is in some cases more than 40 feet below the level now reached by the highest tides, indicating a depression of at least this amount. Here again a tilt seems to have taken place along a more or less N.-S. axis, the sequence of events having been the depression of a forest-clad coastal plain traversed by creeks, followed by a tilt to the east raising the area now occupied by Bombay Island and submerging that covered by Bombay Harbour.

Corresponding to the littoral concrete of the Bombay and Kathiawar coasts is the friable gritty calcareous sandstone full of marine shells, which has been raised above the sea-level in the neighbour-

[69] G. Bysack, et al. Proc. Asiat. Soc. Beng., pp. 91-113 (1888); T. H, D, La Touche, Brit. Ass., p. 800 (1890).

hood of Cape Comorin; most of the shells are comminuted, but one band is recorded containing some unbroken specimens, all of recent species.[90] The rise in Kathiawar appears to have been greater than it was at Bombay; dead oyster beds from five to ten miles away from the highest spring tide mark witness to the recency of the elevation.[91]

An advance of the land is seen in the extension of the Indus delta which averages as much as 133 feet a year; such additions to the coast are aided by the artificial banking of the river.

A sudden deepening of the sea at a distance of 10 or 20 miles from the shore along the Makran coast has been supposed to indicate the presence of a submerged cliff. Raised beaches along this coast, on the other hand, point to upheaval; they consist, according to Vredenburg, of recent or perhaps Pleistocene material.[92] In the Persian part of the Makran J. V. Harrison found that successive uplifts to 400 feet above sea-level have affected recent beaches. The finer material of some of these beaches resembles the "miliolite" of Cutch, but is much less friable and has a much larger percentage of matter insoluble in dilute acids.[93] At the jutting rocky point on the eastern side of the mouth of the Hab river there is a raised oyster bed about 50 feet above high-water mark. Near Cape Monze (Ras Muari), in the immediate neighbourhood, oyster shells attached to the rocks have also been raised 10 or 15 feet above the same datum line, while marine shells of living species are found scattered about the surface of the ground above.[94] To the north, on the east side of Sonmiani Bay, is a cliff probably of marine origin whose present distance from the sea may indicate a rise of the land.[95] The examples quoted in this paragraph belong of course to the Extra-Peninsular region, but are mentioned here since they also belong to the coast.

Off the west coast, the coral archipelagoes of the Laccadive ("The Hundred Thousand Islands") and the Maldive Islands probably mark the site of submerged land, though this is disputed by some.

Local deposits, supposed to have been formed in lakes, have been noticed on the Nilgiri hills of southern India and in the southern Maratha country; no fossils have been found in them nor does the evidence amount to clear proof of lacustrine conditions, though the probabilities are in favour thereof. It has been suggested that they were produced by earth movement but they are more likely the result of land-slips.[96]

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[90] R. B. Foote, Rec. 16, 30 (1883); Mem. 20, 55-56 (1883).

[91] F. Fedden, Mem. 21, 59 (1884).

[92] Rec. 38, 203 (1909).

[93] G. H. Tipper, Rec. 53, 68 (1921).

[94] W. T. Blanford, Mem. 17, 184 (1879).

[95] W. T. Blanford, Mem. 17, 191 (1879).

[96] H. F. Blanford, Mem. 1, 242-244 (1958); R. B. Foote, Mem. 12, 228 (1876).

SOILS.

A detailed consideration of Indian soils is beyond the scope of the present work.[97] Consisting as they do of the surface of the ground altered by the action of air and rain, by impregnation with organic matter, and by the results of agricultural processes, they vary with every difference in the underlying formation, whether it be one of the older rocks or one of the more recent unconsolidated deposits. There are, however, two forms of superficial accumulation which have received repeated notice in geological works on India and require some consideration ; one of the two, the *regur* or black soil, is a very remarkable substance.

Red Soil.—The somewhat ferruginous soils common on the surface of many Indian rocks, and especially of the metamorphic formations, would probably never have attracted much attention but for the contrast they present in appearance to the black soil. They have, in fact, been noticed chiefly in papers relating to the black soil country in the western and south portions of the Peninsula. The commonest form of red soil is a sandy clay, coloured red by ferric oxide and either derived from the decomposition of rock *in situ* or from the same products of decomposition washed to a lower elevation by rain. The term is, however, frequently used in a vague sense, apparently to distinguish such soils as are not black. According to Wadia, Krishnan and Mukherjee, the colour of the Red Soil, derived as it is by meteoric weathering from granites, gneisses, crystalline schists and subordinate rocks rich in ferro-magnesian minerals, is due more to the wide diffusion than to high proportion of the iron content. Compared with *regur* these red soils are poorer in lime, potash and iron oxide, and are at the same time uniformly low in phosphorus content. Some of the so-called red soils are of lateritic origin.[98]

Regur.—*Regur*, a corruption of the Telegu *regada* or of cognate words in related languages, is sometimes spoken of as "black soil" from its colour or as "cotton soil" from its suitability for the cultivation of cotton.[99] It occupies a very large portion of the Indian pen-

[97] The relationship between the soils of India and the underlying country rock is a subject now receiving systematic attention and a preliminary soil map and bibliography was published as early as 1934 (D. N. Wadia, M. S Krishnan and P. N. Mukherjee, Rec. 68, 364-391 and Pl. 25 (1934).

[98] Rec. 68, 367 (1934).

[99] The following are some of the principal writers who have described *regur* :
A. T. Christie. Edin. Phil. Journ., 7, 57 (1829) ;
H. H. Voysey. Journ. As. Soc. Beng., 2, 303 (1833) ;
Newbold. Proc. Roy, Soc. Lond., 4, 54 (1838) ; J. A. S. B., 13, 987 (1844) ; Ibid., 14, 229, 270 (1845) ; Journ. Roy. As. Soc., 8, 252 (1846) ;
Hislop. Journ. Bomb. Br. Roy. As. Soc., V, 61-62 (1853) ;
H. J. Carter. Ibid., 329-331 (1854) ;
W. Theobald., Mem. II, 298 (1860) ; Mem. 10, 229 (1873) ;
H. F. Blanford. Mem. 4, 183 (1862) ;
W. King & R. B. Foote. Mem. 4, 352 (1864) ;
W. T. Blanford. Mem. 6, 235 (1869) ; Rec. 8, 50 (1875) ;
T. Oldham. Rec. 4, 80 (1871) ; R. B. Foote, Mem. 12, 251 (1876).

insula and Newbold has estimated that at least one-third of southern India is covered by it. It is especially prominent in the Deccan and in its properties resembles the characteristic soils of the American prairies, especially the "black adobe" of California. Strikingly similar to the *regur* of the Deccan are the "Chernozoems" of Russia and some of the basalt soils of the South Africa; the latter are described as highly fertile in spite of their low nitrogen content.[100]

In its most typical form *regur* is a fine dark soil which varies greatly in colour, consistence and fertility, but which preserves the constant characters of being highly argillaceous and somewhat calcareous. of becoming strongly adhesive when wetted—a fact easily verified by any attempt to walk across a black soil country after a shower of rain—and of expanding and contracting to an unusual degree under the respective influences of moisture and aridity. Hence in the dry season its surface is seamed with broad and deep cracks, often five or six inches across and several feet deep. Like all argillaceous soils, *regur* retains water and consequently requires less irrigation than more sandy ground; indeed, black soil as a rule is never irrigated at all in the western Deccan, Nagpur and Hyderabad. When dry, it usually breaks up into small fragments; on being moistened with water it gives out an earthy odour. When strongly heated, it is said to fuse into a glassy mass, but this is not invariably the case and is probably dependent on the proportion of iron and lime present. Chemical analyses show that the proportions of iron, lime and magnesia vary but are usually high, and there always appears to be a considerable quantity of combined organic matter, amounting commonly to from 7 to 9 per cent. in undried soil. The black colour seems to be due either to the carbonaceous elements of the soil, or to organic salts of iron, but there is much variation in the tint, which is frequently brownish and sometimes grey. Some interesting experiments by A. Turnbull Christie on the adsorbent power of *regur* have shown that a dried specimen will gain about 8 per cent. in weight after exposure for a few weeks to an atmosphere saturated with moisture.

Regur usually abounds in *kankar,* often in rounded shot-like grains, as in parts of Central India.[101] The purest beds, as a rule, contain no pebbles, but fragments of chalcedony or zeolite are common in the black soil where it is derived from the decomposition of basalt; in southern India *regur* occasionally includes debris of the metamorphic rocks, sandstone or limestone, on which it rests.

Where uncultivated, the plains of black soil in most cases support but few trees and these, as a rule, are of no great size. The principal product is grass, commonly growing to a height of three or four feet and sometimes considerably higher, and what trees there are, are injured or killed by the universal practice of burning this grass annually in the dry season; it is probable, therefore, that the plains of black soil would support forest if left to themselves. The fertility of *regur* is so great that some of its plains are said to have produced

[100] A. L. Du Toit "Geology of South Africa", 2nd Edit., 442 (1939).
[101] Gen. Rep. Rec. 33, 109 (1906).

crops for 2,000 years without manure, without irrigation, and without any fallow period. Some varieties near the coast of southern India are comparatively infertile.

This soil presents its typical appearance only near the surface of the ground; if more than 6 or 10 feet deep, it usually passes down into brown clay with *kankar*. Except where carried down and re-arranged as a stream deposit, it is never met with at any depth beneath the surface.

The distribution of black soil in the Indian peninsula is of some interest in connection with the origin of the formation. Except in the neighbourhood of the coast, *regur* is found everywhere on the plains of the Deccan Trap country. A very similar soil is found locally in the basaltic Rajmahal hills but, with this exception, nothing of the kind is known in Bengal or the neighbouring provinces. In southern India, however, tracts of black soil are scattered throughout the valley of the Kistna, and occupy the lower plains and flats of Coimbatore, Madura, Salem, Tanjore, Ramnad and Tinnevelly; on the Mysore plateau there is but little. Some occurs on portions of the coast plain along the eastern shore of the Peninsula, and the great alluvial flat of Surat and Broach in eastern Gujarat consists of this soil. The soils of Ahmedabad are light-coloured, but *regur* occupies the surface of the depression lying between the head of the Gulf of Cambay and the Little Rann of Cutch..[102]

The origin of *regur,* like that of laterite, has given rise to much discussion in which the Deccan Trap figures largely. In many cases it cannot be questioned that this black soil is directly derived from the basalt by surface decomposition, and it is not surprising that numerous observers have contended that it has so originated in every case. Throughout the immense Deccan Trap area, a passage from decomposed basalt into *regur* may be seen in thousands of sections, and all the alluvial valleys, most of which contain black soil, are filled with deposits derived from the disintegration of basaltic rocks. More than this, the boundary of the Trap coincides approximately with that of the black soil over enormous areas; where the latter is found a little beyond the boundary of the Trap, we may suppose either that the latter existed here at one time and has disappeared through disintegration, or that the soil has been washed down from the neighbouring trap hills. This is admirably exemplified around Nagpur and Chanda in the Central Provinces, where *regur* occurs everywhere upon the Trap, but is never seen upon the metamorphic rocks a few miles to the east, except where there is reason to suppose it has been transported, as in the case of alluvial flats of rivers flowing from the Trap country. Again, whilst nothing resembling *regur* is found in the metamorphic region of Bengal, Bihar, Orissa, Chota Nagpur, Chattisgarh, and the neighbouring provinces, soils indistinguishable from those covering the Deccan Trap are found in the basaltic Rajmahal hills; a similar formation has also been observed in small patches in the Prome district of Burma, derived from the decomposition of basalt.

[102] A. Rogers, Q. J. G. S., 26, 118-120 (1870).

That *regur* is exclusively derived from basalt, however, is not generally accepted. In the first place, as Newbold pointed out, basalt usually disintegrates into a reddish soil, quite different from *regur* in character. The reddish soil can be seen in places passing into *regur*, but the black soil is, as a rule, confined to the flatter ground at the bottom of the valleys or on flat hill-tops, the brown or red soil occupying the slopes. Again, the masses of black soil in the valleys of the Godavari and Kistna might be due to the alluvial deposits having been derived from the trap rocks through which both rivers flow in the upper part of their courses, but hundreds of square miles in the basins of the Penner, Palar, Cauvery and other rivers still farther south, are composed of precisely similar *regur* to that of the Trap area. There is, as we have already seen, no definite evidence to show that the Deccan Trap ever extended to the valleys of the rivers named, and it is generally supposed that the alluvial flats contained in these valleys are mainly formed from the detritus of metamorphis rocks.

Captain Newbold considered all *regur* to be of sub-aqueous origin and compared it to the deposits in the tanks or reservoirs of India, and to the mud of the Nile. H. F. Blanford suggested that the cotton soil of Trichinopoly had accumulated in lagoons or backwaters near the sea, and he showed that in one place, near Pondicherry, *regur* was actually being formed in a nearly dry lagoon separated from the sea by a sand-spit.[103] King and Foote, on the other hand, thought it more probable that the Trichinopoly *regur* was a fresh-water deposit accumulated in marshes.[104] It was shown later that a complete passage takes place in the neighbourhood of Surat between the deposits formed in tidal estuaries and the *regur* of the surrounding country, and it appears probable that much of the black soil of eastern Gujarat may have been originally a marine or estuarine formation.[105] Finally Hislop objected to the theory of sub-aqueous origin, and appears to have been the first to suggest that *regur* may be of subaerial derivation and due to the impregnation of certain argillaceous soils with organic matter.[106] This appears to be the most probable theory. It is now generally agreed that some forms of *regur* originate from the decomposition of basalt *in situ,* others from the disintegration of argillaceous rocks, whilst other varieties again were originally alluvial clays formed in river valleys, or deposited in fresh-water marshes, estuarine flats or salt-water lagoons. The essential character of a dark colour appears in all cases to be due to the admixture of organic matter, and perhaps partly to the presence of a small quantity of iron. It is far from improbable that most of the black soil flats of India were at one time covered with luxuriant forest, before the vegetation was periodically exposed to the effects of fire. The increased dampness of soil, the protection from rain-erosion, and the supply of decomposing vegetable matter may have contributed to the formation of the more fertile

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[103] H. F. Blanford, Mem. 4, 191 (1862).
[104] Mem. 4, 357 (1864).
[105] W. T. Blandford, Rec. 8, 50 (1875).
[106] Journ. Bomb. Br. Roy. As. Soc., 5, 61 (1857).

forms of *regur*. That the process of *regur* formation is a purely superficial one and due to surface action of a past time, is well seen in many of the *regur* plains that have a slightly undulating contour. In such places, while the earth is black on the flats above, where the superficial layer has not been washed away, it is brown where the rain-wash has swept away the surface soil; the black soil washed from the sides of the hollows has frequently accumulated towards the lower part of the latter.

The abrupt termination of *regur* in places along the edge of the Trap country and the rather sudden change from an argillaceous soil to a sandy one is due simply to a change in the nature of the underlying country rock. While the basalt appears generally to decompose into a highly aluminous substance, the metamorphic rocks produce sand to a large extent. At the same time it must be admitted that it is not clear why argillaceous deposits should have taken on the form of *regur* in southern India, whilst nothing of the kind is known in Bengal except in the basaltic region of the Rajmahal hills. A dark coloured soil certainly forms in the marshes of east India but it has not the character of *regur*, and no cotton soil has been noticed in the dense forests of Chota Nagpore and Bastar, with one or two unimportant exceptions, in the forest-clad plains of Burma. It is doubtful whether true *regur* occurs on the Malabar coast between Bombay and Cape Comorin, and the marshy soils on the top of the Western Ghats do not assume the form of cotton soil. The *regur*-bearing plains are practically confined to those parts of India which have a moderate rainfall not exceeding about 30 inches, but it is impossible to say whether this is an essential condition.

To sum up, it may be stated on more or less trustworthy grounds that *regur* has resulted from the impregnation of certain argillaceous material with organic matter, but that the process by which this has taken place is imperfectly understood, and some peculiarities in distribution require explanation.

Peat.—True peat forms in the hollows of gneissic rocks on the Nilgiris and on some of the other mountains of southern India, such as the Shevaroys,[107] at elevations above 4,000 feet, its formation being due, as it is in higher latitudes, to the growth and decomposition of a moss. The living material grows on that which is decayed and the dead vegetation becomes engulfed in the water-logged bog.[108] In the marshes of the Gangetic delta an inferior kind of peat is also formed by the decomposition of various aquatic plants, especially of wild rice.[109] The peat-like beds so widely distributed in the neighbourhood of Calcutta at a little depth below the surface appear to be derived from the decomposition of forest vegetation. A somewhat similar substance has been obtained from beneath a marsh in Oudh.[110]

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[107] R. B. Foote, Mem. 12, 252 (1876).
[108] C. S. Fox, Mem. 57, 239 (1931).
[109] Journ. As Soc. Beng. 23, 401 (1854).
[110] Ouseley, Proc. As. Soc. Beng., 85-86 (1865).

Phosphatic and manganiferous soils.—The soil in southern Monghyr and eastern Gaya has a phosphorus content appreciably higher than that in lands further east, a result due to the presence of apatite in the mica-bearing pegmatites of the neighbourhood. The decomposition of mica-peridotites in the Damuda valley has had the same effect on the local soil.[111]

Examples of manganiferous soils are to be found in the district of Chitaldrug in Mysore, where extensive areas are covered to a depth of two or three feet with dark manganiferous earth yielding as much as 9 per cent. of MnO. Some very manganiferous soil has also been noted near Kumsi in the Shimoga district.[112]

Sources of water in parts of the Peninsula.—Here mention may be made of the *talpargis* of Mysore, which are underground spring-heads excavated in sandy alluvial deposits below the hills and tapped by channels leading off the water for irrigation purposes. Water, percolating through the porous alluvium flows into these channels at depths varying from a few inches to 24 feet below the surface. Seven or eight feet is a common depth at which water is found in a *talpargi.*

Important sources of water in the immense tract of country covered by the Deccan Trap are the more or less porous Inter-trappean beds and decomposed interflow trap horizons below the surface; these are tapped by wells, some of which are of considerable depth.

Saltpetre deposits.—This is a convenient place in which to mention the formation of saltpetre in the Gangetic plain of Bihar and the United Provinces, as well as in the plains of the Punjab. The houses of Indian villages consist for the most part of mud and, as a consequence, frequently tumble down and have to be renewed. The village site thus becomes raised gradually, and as the floors of the houses are commonly made of mud and cowdung, there is built up a nitrogenous deposit, which is reinforced by other forms of animal refuse and to which are added the wood ashes of innumerable fires. The decaying refuse undergoes nitrification, under a climate favourable to the growth and action of nitrifying bacteria, and the product drains into lower levels and separates out as an efflorescence consisting largely of sodium chloride, sodium sulphate and the nitrates of potash and magnesium. These accumulations in some of the old villages are the result of hundreds of years. The production of saltpetre has formed an industry of some importance from very early times; considerable quantities are imported from Nepal into other parts of India.[113]

Loess and drift sand.—Large areas in the Son valley are occupied by loess-like deposits formed by the strong winds of the hot season sweeping over a parched and friable soil. It accumulates in shelter-

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[111] C. S. Fox, Rec. 59, 398 (1926); E. H. Pascoe. Bull. India Industr. & Lab., No. 42, 27 (1929).

[112] L. L. Fermor, Mem. 37, 404 (1909).

[113] Rec. 57, 280 (1925).

ed nooks in the hills and over the broad and open plains. It is a fine-grained, unstratified loam, becoming a slimy, impalpable mud when wet, and is sometimes penetrated by numerous small sinuous and branching tubelets.[114]

Sand drifted by the wind forms low hillocks in many parts of the Indian coast. A series of parallel ridges of sand hills along the shore of Orissa has been supposed to mark successive positions of the shore line. A similar tract of blown sand is found north of Orissa in the Midnapore district, and southwards at intervals throughout the whole of the west coast. The sand, derived from the seashore, is blown up into ridges at right angles to the prevailing wind, with their longer slope to windward and a shorter and steeper surface on the lee side. Smaller patches of sand are sometimes found on the banks of backwaters. The sand-hills frequently extend for two or three miles inland from the coast, and in such cases the inner ridges are clothed with a peculiar vegetation, of which the cashewnut tree (*Anacardium occidentale*) and a screw-pine (*Pandanus*) are conspicuous members. Sometimes, as for instance in parts of Midnapore there is flat and occasionally marshy ground between the ridges, which are parallel to the coast; flats of this kind are probably relics of lagoons which were formed in the usual way by a sand-spit along the seaward side and which became gradually silted up. Assuming that each ridge coincides with a former coast-line, the existence of several parallel ridges probably indicates successive rises of the land.

On the Malabar coast sand dunes are equally common, and contribute in no small degree to the formation of lagoons or backwaters by accumulating on sand-spits. In the northern part of this coast, near Bombay, no sand-hills have been noticed, probably because the detritus from the trap rocks is not a suitable material for its formation; further north, however, in Surat and Broach,[115] in portions of Kathiawar, and in Cutch, blown sand in many places covers more or less ground in the neighbourhood of the shore.

One peculiar form of sand-hill, known as *teri*, is largely developed along the Tinnevelly coast, and to a small extent in the north-western parts of Nellore and in south Travancore. The sand which builds up these hills consists of rounded grains of colourless quartz, stained red—often bright red—by a thin film of ferruginous matter which is easily dissolved by acids. In the Tinnevelly district they owe their origin to the dense clouds of sand and dust blown by the southwest monsoon off the bare red soil plains towards the coast where the wind, meeting the sea breeze, is checked, and the sand dropped to form the *teris*.[116] Similar sands are described by Tipper at Cape Comorin and at Muttum in Travancore, in the older dunes, which lie at a higher level than those forming at the present day. Their bright red colour is due partly to the iron-bearing minerals they

[114] R. D. Oldham, P. N. Datta & E. Vredenburg, Mem. 31, 32-33 (1901).
[115] W. Blanford. Mem. 6, 235 (1869); A. B. Wynne. Ibid., 9, 82 (1872).
[116] R. B. Foote, Mem. 20, 87 (1883).

contain and partly to the lateritic dust blown and washed on them.[117] They appear to carry a larger proportion of monazite than the younger dunes, which are less solid than the older ones though formed in the same manner. At Cape Comorin they are rapidly coming under cultivation.

On the low cliffs south of the Residency at Cape Comorin a deposit of blown sand has been cemented to a hard compact material by calcite. In some of its upper layers are land shells of the genus, *Helix*, but the main bulk of the rock is made up of generally rounded grains of the minerals found on the beach, including monazite, ilmenite, magnetite, garnet and quartz, and in addition numerous calcareous fragments of organic origin such as worn foraminifera.

Sand dunes are not confined to the sea coast but are of common occurrence on many of the peninsular rivers such as the Godavari, Kistna and Cauvery. In some instances villages have been buried by the sand blown from the river beds during the dry season. This has happened in the vicinity of the Haggari river in the Bellary district. During the months westerly winds carry much sand out of the broad bed of the river, which generally dries up entirely, and pile it up on the right bank into dunes of some size, to the great detriment of adjoining villages; Bodurti, eight miles from Honur, was totally buried in 1826-1827 and covered by sand except for the tops of the walls, while Jiraganur, two miles north of Haggari station is a more recent example of the easterly advance of these blown sands from which protrudes the ruined village temple. The dunes of the Haggari rarely attain an elevation of 20 feet and none of them exceeds 30 feet.[118]

EVIDENCE OF A COLDER CLIMATE IN THE PENINSULA

There is no physical evidence in the Peninsula, either in its hill ranges, its numerous Pleistocene river deposits or its cave deposits, of recent glacial conditions. In the Himalaya, as will be seen, there is everywhere abundant evidence of the glaciers having extended to lower levels than they now reach; ancient moraines and other signs of glacial action have been noticed at elevations varying from a little under 5,000 to 8,000 feet. There is thus positive and unmistakable proof of a post-Tertiary period colder than the present.

In the Peninsula such indications are as follows. On several isolated hill ranges, such as the Nilgiri, the Anamalai, the Shevaroys, and other disconnected plateaux in southern India, as well as on the mountains of Ceylon, there live a temperate fauna and flora which do not exist in the low plains of that region, but are closely allied to the temperate fauna and flora of the Himalaya, the Shillong plateau (Garo and Khasi hills), the Naga hills, and the mountains of Malaysia and Java. Even on isolated peaks such as Parasnath (4,500 feet) in Bihar, and on Mount Abu in the Aravalli range,

[117] Rec. 44, 189 (1914).

[118] R. B. Foote, Mem. 25, 11, 187 (1895).

several Himalayan plants exist. The occurrence of a Himalayan plant like *Rhododendron arboreum*, and of a Himalayan mammal like *Martes* flavigula, on both the Nilgiris and the mountains of Ceylon, will serve as examples. A considerable number of less easily recognised species might be cited. Hooker mentions twelve species of trees and shrubs common to the Nilgiris and the cool regions of the distant Khasia, Manipur and Naga Hills; the herbaceous plants common to the Nilgiris and the Khasia hills are too numerous to mention. ("Sketch of the Flora of British India", 1904, p. 33).

In some cases there is a closer resemblance between the temperate forms found on the Peninsular hills and those on the Shillong plateau than between the former and Himalayan species, but there appear also to be connections between the Himalayan and Peninsular temperate regions which do not extend to the eastern hills. An interesting example of these is the occurrence on the Nilgiri and Anamalai ranges and on some hills further south, of a species of wild goat, *Capra hylocrinus*, belonging to a sub-genus, *Hemitragus*, of which the only other known species, *C.* (*Hemitragus*) *jemlaica* inhabits the temperate region of the Himalaya from Kashmir to Bhutan; this case is remarkable because the only other wild goat found completely outside the Palaearctic region is another isolated form on the mountains of Abyssinia.[119] On the top of Parasnath occur the lizard, *Lygosoma sikkimense*, the beetle, *Thynsia wallichi*, the cicad, *Haphsa nicoonache*, and a fly, *Sepsis cynipsea*, none of which is known in the plains of India except in close proximity to the base of the Himalaya.

In estimating the value of these resemblances, due weight must be given to the fact that the range in elevation of the temperate fauna and flora of the orient in general appears to depend more on humidity than temperature. For example, many forms which are peculiar to the higher ranges in the Indian hills are represented by allied species at lower elevations in the damp Malay peninsula and archipelago, and some of the hill forms are even found in the damp forests of the Malabar coast. That a great portion of the temperate fauna and flora of the hills of southern India has inhabited the country from a much more distant epoch than the Glacial period may be accepted as almost certain, there being so many peculiar forms. It would be possible for the species common to Ceylon, the Nilgiris and the Himalaya to have migrated at a time when the country was damper, without the temperature being lower, but it is difficult to understand how the plains of India could have experienced a damper climate without either depression, a change in the prevailing winds, or a diminished temperature sufficient to check evaporation. A depression would have caused a large portion of the country to be inundated by the sea, a change which in itself would have prevented rather than aided the migration of animals and plants. A change in the prevailing winds would have been improbable so long as the

[119] The fact that *Hemitragus* existed in India during Miocene and Pliocene times does not appear to vitiate the deduction drawn in our text (See Pilgrim. "Postglaziale Klimaveranderungen", Stockholm, 1910, 442).

distribution of land and water was in general what it is today. There are some grounds for accepting the remaining theory, therefore, that the temperature of the intervening plains was for an appreciable period sufficiently lower than it now is to permit some of the animals and plants from the Himalaya to wander south.

II. EXTRA-PENINSULAR REGION OF INDIA.

In the Extra-Peninsular area we find Recent and sub-Recent river gravels in every valley, but the more extensive accumulations, if we except the alluvium of the Irrawaddy river, are all found in rock-bound basins of closed or arrested drainage.

Country west of the Indus.—The Chagai district and the north-western portion of the Kalat State of Baluchistan, together with the borderland of Afghanistan and Persia, comprise irregular and vaguely defined hydrographic basins of closed drainage, due to the very scanty rainfall.[120] In fact, behind at least some of the mountain loops which continue the line of uplift of the Himalaya westwards and south-westwards, we find plateau country corresponding to that of Tibet with similar salt lakes and a climate of increasing desiccation. Eastern Persia, for instance, is such a tableland, the drainage of which finds its way into a series of land-locked depressions—salt marshes or mud flats—known as *hamun* or *kavir*. The majority of the small rivers carry water only after the melting of the snows or immediately after the rare showers of heavy rain, and there is overwhelming evidence that precipitation has been and still is decreasing; in support of this is the large number of abandoned *karez* or *kanat*—sub-soil drains used in the drier parts of Persia and Baluchistan and described below.[121]

To the scarcity of rain is due the absence in western Baluchistan and its borders of any well marked river course possessing an individuality of its own. E. V. Vredenburg remarks: "where the mountain ranges overlook the desert plain, innumerable dry channels follow the slopes parallel to one another. They never contain any water except for a few hours at a time in the rare event of a shower of rain; not one of them contains a stream running even for part of a season, such as would excavate its bed more deeply and gradually draw towards it as tributaries the supply of the neighbouring channels. Each of these furrows runs from the hill into the plain, following an almost straight course absolutely independent from its neighbours".

In the dry country west of the Indus there are extensive accumulations of Recent deposits, of which only a small proportion can be regarded as alluvium in the true sense of the word. Beyond the Sind frontier there are immense stretches of blown sand and less in western Baluchistan and Afghanistan, of which very little is known, but it is probable that they are composed principally of the

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[120] E. Vredenburg, Mem. 31, 187 (1901).
[121] G. H. Tipper, Rec. 53, 53 (1921).

same types of accumulation as are seen in the smaller valley plains around Quetta.

First among them, as being the oldest, is a series of more or less bright red clays, sands and gravels which have been regarded by some as Tertiary.[122] Though these beds occur in close proximity to typical Siwaliks, no contact has yet been observed, but there are indications that they are newer than the Siwaliks, and they appear to be intimately connected with Recent deposits. It is at any rate certain that they were deposited after the main features of the orography had been marked out by disturbance and erosion.[123] These deposits are frequently undisturbed, especially towards the centre of the valley plains and are then difficult to distinguish from more recent deposits, except that the latter are seldom of so deep a red colour. More usually, however, they have undergone some slight disturbance, which has enabled the drainage to cut into them and form an irregular surface dotted with small hills devoid of soil or vegetation as a result of the saline nature of the clays and the steepness of their slopes. Towards the margins of the valleys, where these deposits abut against the hills, they are sometimes tilted up at high angles of dip, as in the Mashalak range west of Quetta.

The most important of the Recent deposits of these plains are the extensive gravel slopes at the foot of the hills and the loess.

The great gravel slopes which everywhere fringe the foot of the hills, and often reach a width of many miles in this comparatively rainless country, form one of the most conspicuous features in the scenery of the more open parts of the hill region west of the Indus. This talus is known as the *daman* or "skirt" of the mountain, and occurs in great inosculating fans spreading with a slope of from 300 to 600 feet per mile from the mouths of the stream valleys. It is into these fans that long underground tunnels, known as *karez* in Baluchistan and as *kanat* in Persia, are driven, with a slope less than that of the surface though in the same direction, till they pass below the level of permanent saturation and, acting as a sub-soil drain, carry the water out.

Western Baluchistan, southern Afghanistan and a small adjoining tract in Persia are occupied by a great sandy desert divided into two portions by the Chagai hills which act as a watershed between two drainage systems. Of the latter the more northerly is a closed system and appears to consist partly of tributaries to the Helmund and partly of small water-courses feeding the Gaud-i-Zirrek (Shalag Hamun). The more southerly system, with which we are concerned, is also entirely closed, all the ill-marked water-channels draining towards the large lake-basin known as Hamun-i-Mashkhel. This part of the desert covers large parts of Chagai and Kharan, and is interrupted by the hills of the Ras Koh. Very little water ever reaches the lake-basin which for nearly the whole year is a barren plain of

[122] G. L. Griesbach, Mem. 18, 18 (1881); W. T. Blanford, Ibid., 20, 115 (1883).

[123] R. D. Oldham, Rec. 25, 36 (1892); Mem. 18, 18 (1891); Ibid., 20, 115 (1883).

sun-cracked alluvium, and most of the water-courses lose themselves in the desert. Where they traverse harder material such as limestone, the narrow rift-like gorges are known as *tangi*. They form a very characteristic feature of this country, alternating along the course of the stream with broad open valleys occupied by clay; the precipitousness of the sides of the gorges is assisted by the absence of vegetation and the consequent reduction of chemical action on the hard limestones. Another contributing factor to the steepness of these gorges is the lack of moisture, the result being that the night frosts are almost entirely deprived of their power to disintegrate the rock. As a consequence, the steep sides of the ravines cut by the streams, where they meet with compact rock remain standing almost perpendicular, while in the stretches of soft clay intervening between the gorges, the valley widens out. The *tangis*, etc., of Baluchistan are an excellent example of the manner in which a stream maintains its course through hill ranges as they slowly rise across its path in response to a compressional earth movement. They are the product of antecedent transverse drainage across anticlinal folds which have left behind hard limestone ridges, the erosion of the channel keeping pace with the local upheaval. The rate of elevation in some cases appears to have been too great for the stream, and some at least of the areas of closed drainage so common in Baluchistan are thought to have been the result; in these, extensive deposits of alluvium and wind-blown loess have usually accumulated.

Filling the great depressions between the groups of hills in this desert region are conglomerates and sands. The *daman* or talus of conglomerate or gravel skirting the ranges has a gradient which is so low that, as Vredenburg observes, the eye hardly realises the great height it attains up the hill slope against which it is banked. The dwarfed appearance of the hill ranges, notwithstanding their altitude, is thus explained. The talus, which attains proportions comparable with those of the hills from whose debris it is formed, is extremely variable in composition, coarse conglomerate or gravel and finer deposits alternating in a very irregular manner.[124] Some of the coarser deposits are eminently permeable, and the water supplied by the scanty rainfall, unable to effect any appreciable erosion and transport, becomes stored therein and protected from evaporation. Such natural reservoirs provide the water supply of the country; the water is tapped by *karez* which, however, are gradually being superseded by artesian wells.

An unusually heavy shower, Vredenburg, notices, will occasionally cause a flood, carrying many of the boulders and pebbles into the plain. Such floods, which were probably more frequent in former times, have spread the pebbles over large areas in the desert, producing the stony plains known as *dasht*. The black colour of the pebbles, due to the oxidation of iron compounds, adds to the sombre and desolate appearance of these dreary plains, which occupy immense areas not only in Baluchistan but throughout Persia. In

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[124] E. Vredenburg, Mem. 31, 188 (1901).

most of the ill-defined water-courses the water becomes ponded back by irregularities of the ground into shallow pools which cover large areas but dry up in a few days or even hours, leaving behind a fine, light-coloured mud. The latter accumulates in time to form a plain or *pat* which may show patches of saline efflorescence; though mostly more barren even than the stony plain, it is sometimes capable of cultivation when water is available from some neighbouring *karez* or weil.

"These *pats*, often half-concealed by the ever-encroaching sand dunes, pass imperceptibly into the stony *dasht*, and possess usually very ill-defined limits. Where, however, they become of considerable size, and where they are fed by streams that can give rise to more or less permanent sheets of water, they exhibit a more distinct line of shore, and gradually merge into the class of shallow lakes called *hamun*. The Lora Hamun, which is now absolutely dried up, is nothing more than a gigantic *pat*. The Hamun-i-Mashkhel, dry for the greatest part, still contains water in two depressions, now separate, but which some of the oldest inhabitants of the district remember having seen once united. The Gaud-i-Zirrch is described by Captain McMahon as 'a lake of salt brine fringed by an ever encroaching margin of solid salt.' It may be mentioned that these three lacustrine depressions lie at very different altitudes. The Lora Hamun is at an altitude considerably higher than the two others, and yet appears to be perfectly independent from them. Moreover, the drainage areas of these important depressions are by no means co-terminous, but are separated by a number of minor independent depressions. Occasionally one of these may be unusually deep and, owing to some exceptionally favourable water-supply, may allow the formation of a perennial sheet of water. These small ponds are called *nawar*. They are usually surrounded by a cultivated oasis and supply water to the nomads and their flocks often to great distances "Shady tamarisks, many centuries old, grow by their banks, and the women who come to fill their "*mashks*" with water, the sheep, cattle and camels which in countless flocks come to quench their thirst, form a busy scene which affords a strange contrast to the awful silence and desolation of the surrounding desert."[125]

Except in the most unusual event of a storm, the broad winding stony plains are absolutely dry, and the flood, when it does sweep through it, seldom lasts more than an hour, the water-rushing along a network of irregular and ever-shifting furrows, rolling along large boulders which rattle loudly as they come into collision with one another. These floods by their suddenness are a source of danger to the flocks, especially to the smaller animals like sheep and goats, which may be knocked over by the moving boulders and carried away by the flood.[126]

The conglomerates or gravels of the *dasht* are in some places arranged in terraces which are believed to form concentric belts surrounding at a distance some of the larger lake basins. If this be correct, they would appear to mark the position of ancient shore lines of much larger lakes which have since either dried up completely or shrunk to the shallow marshes and salt swamps of the modern *hamun*. The successive lines of gravel escarpment would represent temporary periods of rest during the desiccation of these great water areas. Confirmation of this shrinkage is described by Vredenburg

[125] E. Vredenburg, Mem. 31, 190-191 (1901).
[126] E. Vredenburg, Mem. 31, 193 (1901).

who found that the slopes of scattered islands in the Lora Hamun exhibit, sometimes almost up to their very summits, patches of the same buff-coloured mud which covers the floor of this dried-up lake; it is impossible for the mud on the islands to have been derived from the rocks composing them, for these rocks consist of old volcanic rocks and limestones of the Flysch period. Vredenburg calculates that the Lora Hamun was at one time a lake 50 feet deep in the centre, and covered an area three or four times that of the plain which now bears its name. There is, therefore, reliable evidence that climate conditions in the past were less of a desert nature than they are today. In those days a more abundant rain-fall was responsible for the distribution of pebbles over the entire width of the desert; today the water-courses pass abruptly from the conditions of a mountain torrent to those of a delta—for the fan talus of gravel is nothing but a small delta—with no intermediate stage. Old artificial dams across many of the ravines are proof that the country, which now appears to be uninhabitable for want of water, was at one time supplied with perennial springs.

The complete desiccation of this region has encouraged the development of the most characteristic feature of desert scenery, the accumulation of wind-borne sand. Only the transverse type of dune is seen; the crescent-shaped dunes known as "barchanes" or "medanos" are present everywhere with their typical characters. Entire ranges of hills have been buried beneath the sand between Amir-Chah and Saindak.

The loess deposits consist of a fine-grained, usually grey-coloured, unstratified accumulation of wind-blown dust, precisely similar to the great loess formation of China. They vary in size from small patches of a few yards across to great plains like that of Thal Chotiali. The important role they play in the question of water supply is well described by Vredenburg. In the Quetta region especially, the *daman* or fan talus which spreads out from the foot of the mountains is built up of alternating layers of loose permeable gravel and highly impermeable loess-like silt of fine texture and argillaceous composition. The layers of gravel decrease in coarseness as they slope towards the plain; in the other direction, *i.e.*, towards the apex of the talus fan they not only become coarser but come into contact with one another by reason of the dying out of the layers of loess. Owing to the torrential nature of the rivers and the peculiar structure of the alluvial fans, the gradients are high, so that there is a considerable difference of level between the coarse gravels at the head of each fan and the plain over which the deposits have been distributed. "The coarse nature of the deposits at the head of the slope of the *daman* favours percolation; the water gradually finds its way into the buried tongues of gravel, and the impermeable clays which enclose these gravels prevent all natural escape, thus producing an artesian reservoir which is eminently of the 'perfect' type."[127] In the Kachi, as the plain south of Sibi is called, the

[127] E. Vredenburg, Mem. 32, 25 (1904).

deposits of the plain appear to be principally wind-blown loess, more or less mixed with true alluvium.

Closely connected with the true loess is a more or less finely stratified type of deposit, which is formed in the low-lying parts of loess plains. After every heavy shower the drainage from the higher portions of the plains, as well as from the surrounding hills, collects in these depressions, whence it gradually disappears by percolation and evaporation. The water when it first collects always carries a large amount of solid matter in suspension, which is deposited when it comes to rest, the coarser particles sinking first. By a repetition of these floods, a finely bedded accumulation of alternately finer and coarser grained material is formed, which presents a great similarity to a lacustrine formation, though not deposited in a lake in the true sense of the word but in merely temporary collection of flood water.

Coastal features and deposits of Sind and Baluchistan have already received attention (p. 1739).

The volcanoes of Chagai.—In the western half of Chagai are some recent volcanoes, now extinct, which require notice. The most important of these is Koh-i-Sultan, a mountain mass 17 miles long and some 10 miles across, occupying an inaccessible position in the heart of the desert, and almost entirely devoid of vegetation. It comprises three distinct but greatly denuded cones, whose centres are disposed along a straight line directed W.N.W.-E.S.E., *i.e.*, parallel to the tectonic grain of the country.[128] The alluvial plain to the north is strewn all over with pumice.

The earlier eruptions, according to Vredenburg, were mostly explosive and gave origin to large accumulations of tuff; capping these are the later effusions of lava which at one time formed a continuous covering but have been reduced by the action of water-courses to isolated gently sloping plateaux surrounding the mountain. The original summits of the three cones have been entirely denuded away. The western cone has thus been worn down to a large circular plain, 4½ miles in diameter, shut in by cliffs consisting almost solely of ash beds. The middle cone is more irregular in shape and more heterogeneous in composition; it contains a large proportion of lava which occurs principally in its central part. The eastern cone has been denuded into large scarped masses, mostly of fragmentary material, greatly decomposed by solfataric action and grouped in a circular manner; it includes the point of greatest altitude, the "Miri", 7,656 feet. The most westerly cone is probably the oldest, and the most easterly the youngest, but eruptions from the different centres have to some extent overlapped each other. The wonderful echoes given back by the cliffs of Koh-i-Sultan have given rise to an interesting myth concerning a magic drum.

Vredenburg distinguishes three cycles of lava flows, the oldest interbedded with the ash beds and agglomerates. The latter suffered extensive denundation before the lavas of the second cycle, which are of considerable thickness, were poured out. The youngest lavas,

[128] E. Vredenburg, Mem. 31, 188 (1901).

probably the latest products of activity, occur at the junction of the middle and eastern cones, and are more basic than the others; they have a distinct columnar structure and have adapted themselves to a topography not unlike that of the present day.

The fragmentary material includes angular masses up to a foot across, and a few volcanic bombs. The disintegration of these ashes and agglomerates has produced an enormous deeply-ravined talus encircling the mountain and reconsolidated into beds scarcely distinguishable from the original deposits. The flows and the blocks in the agglomerate are of an andesitic lava with a somewhat peculiar hornblende. In its last stage the volcano seems to have been a solfatara, and one of the most striking features of Koh-i-Sultan, seen especially in the eastern cone, is the chemical change effected in the rocks by solfataric action, which has changed their normal grey colour to various shades of salmon pink, buff, green, mauve and many other tints. The brightly coloured clays to which much of the material around the Miri has been reduced, are impregnated with alum which effloresces in white tufts and is extracted and used as a mordant. A little sulphur is also extracted from these beds, and the bright red clay is used for marking sheep. Another result of the solfataric action is silicification.

West of the Koh-i-Sultan rises the truncated cone of Damodim, about 4½ miles in diameter, the outer portion of which is a talus including some boulders of very large size. The crater appears to have become choked with the products of denudation. Far more recent, in the opinion of Vredenburg, are some smaller cones of the Puy type in the neighbourhood of Koh-i-Sultan, made up entirely of lava. There is not much talus around them and the lava appears to have been erupted in a viscous condition and to have solidified at high angles without flowing to any distance. The best known are the Koh-i-Sultan, the Batil Koh and the Mit Koh. The Batil Koh rises from the talus of Koh-i-Sultan, fragments of which have been caught up in the Batil Koh lava. The Batil Koh lava contains clear grains of olivine; the lava of Koh-i-Dalil is a trachytic andesite with a scoriaceous surface.

All these volcanoes of Chagai form the eastern portion of a large volcanic district which occupies a large part of eastern Persia, and includes the lofty Koh-i-Tufdan (13,034 feet) and the Koh-i-Basman, both of which show signs of present-day activity. Recent lavas are found in the neighbouring Persian Makran.[129]

The central portion of the plain in upper Sind is traversed by the present course of the Indus and is higher than the country to the westward and than part of the tract to the eastward. Consequently a belt of marsh extends from north to south at some distance from each bank of the river. That to the west lies not far from the foot of the Kirthar range and terminates southwards in the shallow Manchhar Lake, with its fine fish. This lake is some 12 miles long and 6 or 7 miles broad in the dry season, but covers as much as 180

[129] G. H. Tipper Rec. 53, 68 (1921).

square miles during the inundation season; it is an expansion of the Western Nara which feeds it and of the Aral which drains it into the Indus.[130]

Alluvial deposits of the Northwest.—On the great plains of Rawalpindi, Bannu and Peshawar, exist extensive deposits of gravel, sand and silt; similar deposits are also found north of the Kala Chitta in the Campbellpur or Attock basin, which is over 15 miles long and at least 9 miles wide. The first-mentioned plain, known as the Potwar has been more closely examined than the other two and presents features of some interest. Two types of alluvium are distinguishable, an older and a younger. The former, of Pleistocene to sub-Recent age, succeeds the Boulder Conglomerate of uppermost Siwalik stage in some places with perfect conformity, in others with visible discordance; it is generally distinguishable from the younger buff or light brown alluvium by its warm red and pink colour. While the younger alluvium is full of *kankar*, the older is more impregnated with soda salts (*kallar*).

The older alluvium is but a continuation of the Siwalik sequence and has yielded fossil teeth and bones of living forms such as the camel, horse, ox and dog, as well as a large number of Palaeolithic flints and tools which are especially abundant at certain sites. Palaeolithic tools, however, are not restricted to this horizon but are found in the topmost layers of the Boulder Conglomerate below as well as in re-deposited Potwar silt and younger silts and gravels above.[131] Along the northern slopes of the Range these beds are probably as much as 1,000 feet thick and comprise brownish gray sandstones and conglomerates with some grey fossiliferous clays. Along the range they transgress on to the Eocene limestones, in such cases often dipping steeply, sometimes even vertically; in some places, according to Gee, the Eocene (Sakesar) limestones have been definitely thrust over sandy clays which appear to belong to this Pleistocene sequence. Further north, towards the axis of the broad Sohan syncline, the beds thicken to 1,500 feet in some places and consist of red silty clay, gravel and pebbly grit; the angle of inclination at the same time lessens and over a considerable tract ranges from 5° to 8°.[132] Although corresponding apparently to the Older Alluvium of the Ganges valley, these Potwar deposits are described as free from *kankar*. The newer alluvium of the Potwar, corresponding to the *khadar* of the Ganges plain, is a brown and buff, loess-like slit, with occasional sands, clays and bands of coarse gravel. The basal bed is often a thin gravel, sometimes with unworn Palaeolithic implements. The bulk of this formation, which is usually from 500 to 800 feet thick, is typically a uniform, unconsolidated, unstratified, structureless wind-borne drift, showing no inclination and spread indiscriminately over

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[130] W. T. Blanford, Mem. 17, 23 (1879).

[131] Numerous Palaeolithic implements of human workmanship, constructed of quartzite and trap. have been recently discovered by Lieutenant K. R. U. Todd little south of Pindigheb on the surface of a small sandstone plateau (Mem. Connect. Acad., 8, Art. 1, 9 (1934).

[132] D. N. Wadia, Quart. Journ. Geol. Min. Met. Soc. Ind., 4, 71 (1932).

depressions, slopes and high ground. Although easily eroded, these deposits show a remarkable capacity for standing in high vertical walls, and have been deeply dissected into a labyrinthine network of steep ravines known as *khuddera,* giving rise to a "bad-lands" topography; in some of the more deeply excavated country ravines 300 feet or more in depth are not uncommon.[133] The change from the river gravels and sands of the older alluvium to the mainly aeolian newer alluvium in these parts indicates a desiccation of the surrounding country and may have been due, either to the gradual capture of the Siwalik river by the Ganges, an hypothetical episode to which further reference will be made in the last chapter, or to capture of lower portions of the Siwalik river by its own tributaries, the Chenab, Ravi, Beas and Sutlej.

The Pleistocene conglomerate and even the older alluvium of this area have been disturbed by recent earth movement. On the Salt Range plateau, east of Sakesar, the Lowest Siwaliks (Kamlials) are unconformably overlain by thick deposits of bluff-coloured, semi-consolidated sandstones and conglomerates with subordinate grey clays, dipping at from steep to moderate angles, the angle of inclination decreasing to the horizontal as the more recent alluvium of the valley is approached. Two miles southeast of Sodhi in the same area, Nummulitic limestones have been thrust over alluvium of this sub-Recent type; at the foot of the scarp at several places the alluvium is inclined. In the middle portion of the range, near Katha, the Saline series and Purple Sandstone have been thrust over sub-Recent alluvium and conglomerate, the former being indistinguishable in type from the Recent alluvium of the adjoining plains.[134]

Similar fine-grained alluvial sands and loams, partly wind-borne, form the plains to the south of the Salt Range, interrupted along the foot of the range by boulder fans from the hill streams, and by older sediments of probably Pleistocene age; the latter, occurring in close association with the Saline series, include soft red and brown sandstones, clays, conglomerates and unconsolidated sands and grits. In the conglomerates are pebbles of the Purple Sandstone and other local rocks, as well as derived foraminifera and plant fragments. These beds are either horizontal or dip at gentle, moderate or sometimes steep angles, the inclination being in many cases due to tectonic folding or thrusting, and not to the landslips so often seen along the scrap.

"Erratics" of the Punjab.—The origin of certain erratic blocks, some of them of considerable size scattered over the northern half of the Potwar and seen also on the large alluvial tract of the Campbellpur basin north of the Kala Chitta, has been and still is a matter of dispute. They are abundant along the Indus as far up as Amb on the left bank of the river, in the gorge of the Siran and for some miles below Campbellpur. A few miles W.N.W. of Campbellpur is a group of these blocks, the largest of which is of granite and has a

[133] D. N. Wadia, Mem. 51, 290 (1928); G. De P. Cotter, Ibid., 55, 123 (1933).
[134] E. R. Gee, Private Communication.

girth of 50 feet and a height of from 6 to 8 feet; another nearby has a girth of 48½ feet and a height of 12½ feet, and is of basalt. These erratics lie on alluvium.[135] East of Campbellpur Cotter notes two blocks of gneissose granite and one of Hazara Slate, all lying upon the Kioto Limestone. Many have been found around Jand, a village in the northwestern Potwar, north of the Sohan river. These are composed variously of coarse granite, syenite, fine-grained granite, schist, dark slate, and granite-gneiss, resting most of them upon a sandy deposit containing abundant boulders; this deposit is described by Cotter as having the unsorted appearance of a glacial accumulation. Three large boulders of travertine are seen resting on Chinji rocks northwest of Pindigheb, and a block of Hill Limestone has been observed by Lahiri in the bed of the Nara stream near its junction with the Indus; others of gneissose granite are reported by the same observer some twelve miles W.S.W. of Pindigheb. The most southerly occurrence is one near the village of Trap, on the lower course of the Sohan. In places such blocks have been found as much as 20 miles away from the banks of the Indus. One of the most interesting occurrences is a moraine-like deposit found by Cotter between the Kawa Gar and a low ridge of Hill Limestone near Campbellpur; the deposit is an unsorted mixture of boulders, one of them some twelve cubic feet, consisting of Attock Slate, Giumal limestone, Nummulitic limestone and occasionally gneiss, in a matrix of sand and gravel. It was in this or a neighbouring gravel cap that De Terra and De Chardin found glacially facetted boulders as well as large erratic blocks.[136]

From the presence of Attock Slate and gneissose granite of Himalayan type among the boulders, it must be concluded that the latter came from the mountains to the north. There is in the Attock district no trace of glacial conditions beyond the presence of these erratics which, there is no doubt, are or were at one time moraine material. Cotter, therefore, attributes their presence to some catastrophic flood of sufficient force and magnitude to sweep down such coarse glacial debris from the Indus valley above the Attock plains. Whether such floods, which will receive further mention in the next paragraph, could ever have lifted the enormous rock masses now represented by the erratics is disputed. Coulson, in a recent publication,[137] points out, assuming such transport to be possible, it is more likely to have been effected by the Dore river before it became a tributary of the Indus and at the time when it joined the old Siwalik river which flowed from east to west across the Potwar area; at the same time he prefers to regard the erratics as dumped at their present localities by glaciers entering the Siwalik river. These boulders occur both singly and in moraine-like accumulations, and it is no strain upon our credulity to suppose that glaciers from the north may at that time have reached such low levels in these parts. It must be remembered that the latitude of the country now carrying

[135] G. De P. Cotter, Mem. 55, 124 (1933).
[136] Proc. Amer Phil. Soc., 76, 794 (1936).
[137] Rec. 72, 422-439 (1938).

the erratics exceeds 33°, and that the temperature today drops to low levels during the winter months. In the Kangra district of this province there is reason to believe that glaciers once reached to levels below 2,000 feet.[138] It is not suggested that Attock and the Potwar were permanently ice-bound from year to year, but merely that some of the largest glaciers, or possibly broken-off floating portions thereof with their debris reached as far south as the northern Potwar, perhaps during some abnormally cold season.

As is well known, the Indus is subject to extraordinary floods, caused by a blocking of the upper valley by landslips or ice followed by the sudden destruction of the barriers thus formed. Such floods occurred in 1841 and 1858, and have doubtless taken place in past ages. The great flood of 1841 was caused by the bursting of an earthen dam formed by the collapse of a spur of Nanga Parbat as the result of an earthquake. Behind the dam water accumulated till it was estimated to be 900 feet deep in one place, and formed a lake 35 miles in length, reaching back almost to Gilgit town. Prior to this flood the Indus at Attock (Campbellpur), 260 miles below the obstruction, was fordable. During the flood it rose about 100 feet at Campbellpur, while the waters of its tributary, the Kabut river, were checked and driven backwards for a distance of 20 miles.[139] The flood of 1858 was less violent and was the result of the subsidence of a mountain-side called Phungurh on the left bank of the Hunza river, about a day's march above the Fort of Hunza (Baltit). For six months water accumulated behind this dam. the bursting of which caused a rise of 55 feet in 7½ hours in the Indus at Campbellpur. The waters extended over the Chach plain, and rolled over the stream of the Kabul river, filling up its channel and adjacent low ground to a length of thirty miles from the junction, with an average breadth of more than two miles, and a depth of 60 feet above the original level of the stream near the junction. The Kabul river acted as a safety valve and, at the expense of much destruction of this well cultivated tract of country, saved the lower valley of the Indus. Dams formed by the projection of transverse glaciers into main valleys may also result in serious floods ; as a rule, they appear to be somewhat less dangerous than earthen dams and sometimes act as weirs over which the water passes smoothly and without interruptions of any great violence. Enormous quantities of detritus must be carried down after the bursting of such dams, whether of earth or ice. If, as appears probable, the low temperature of the glacial epoch was felt in India, lakes formed by these obstructions at heights of 5,000 or 6,000 feet above the sea would have been deeply frozen in winter, and large blocks of rock from the river bed and dam might easily have become embedded in the ice, carried down thereby to lower levels on the removal of the dam, and deposited over the inundated country. Heaps of stone and gravel of all sizes are known to be brought 80 miles down the Shyok, one of the tributaries of the upper Indus in Ladakh, by blocks of ice. Cotter's suggestion is that

[138] H. B. Medlicott, Rec. 9, 56 (1876).
[139] Major K. Mason, Him. Journ., Vol. 1, 12 (1929).

the transport of the Potwar and Attock erratics may have been effected without the agency of ice, simply by the overwhelming force of the suddenly liberated mass of water.[140] In 1841 the Indus is described as coming down in a wall of mud.[141] These avalanches of mud and boulders are known in the Himalayan region as *shwas*.

The Bannu and Derajat plains.—On the west side of the Indus, in the Marwat range and at Shekh Budin, T. O. Morris has discovered a glacial boulder bed in a formaton which was referred by him to the Nagri stage of the Siwalik series but which more probably belongs to the Pleistocene (Boulder Conglomerate stage).[142] In Bannu and Derajat the topmost Siwalik stage of coarse ferruginous grits, abundant conglomerate bands, and subordinate clays, measuring considerably more than 2,200 feet, shows dips as high as 60° in contact with undisturbed alluvium. Both older and younger alluvial deposits are seen in this region, the former in some places tilted to 8°. Within the hills the stream courses are terraced, five such terraces of gravel and silt being recorded in one place.

Waziristan.—A large stretch of gravel and boulders above Kaniguram in Waziristan contains much angular and unworn material of unsorted sizes ranging from fine silt to angular boulders weighing many tons; it lies some 6,000 feet above sea-level and may be primarily glacial.[143]

The Salt Range Lakes.—Here mention may be made of the salt lakes found along the northern slopes of the Salt Range. Ignoring mere depressions flooded after unusual rain, there are four permanent lakes or *kahars* as they are locally called. From west to east these are : Son Sakesar or Samundar, the largest, nearly 3 square miles in area during ordinary seasons; Jalar Kahar; Kabakki Kahar; and the nearly circular Kalar Kahar. The Jalar Kahar, five miles south-east of Son Sakesar, though shallow and flat-bottomed, lies in a deep valley among rugged hills, on the axis of an anticline exposing Productus Limestone; the original outlet of the valley to the east has been dammed by deposits of loess, but the depression of that part of the valley floor occupied by the lake may have been caused partly perhaps by faulting and partly by earth movement, according to La Touche.[144] The other three lakes are all open, shallow and flat-bottomed and, in the opinion of La Touche, have been produced by earth movements and not by solution of the Nummulitic limestone on which they lie. None of the lakes has any present visible outfall except the Kalar Kahar and that only when flooded; in the case of the Son Sakesar, coarse detritus at its eastern end may conceal a former outlet. All the lakes are salty, though far removed from, and higher-lying than, the Saline series of the Salt Range scarp; though they all occupy rock basins in limestone, their present

[140] Rec. 61, 327 (1928).
[141] A. Cunningham, Ladakh, Physical, Statistical and Historical, Lond., (1854); T. G. Longstaff, Geogr. Journ. 35, 648 (1910).
[142] Q. J. G. S. 94, 385 (1938).
[143] Murray Stuart, Rec. 54, 93 (1922).
[144] Rec. 40, 50 (1910).

configuration is in all cases due to the irregular accumulation of wind-blown loess. Each of them is slowly silting up. In the vicinity of Son Sakesar, many Palaeolithic artifacts have been found in a terrace of the lake deposits, attributed by De Terra to the older Pleistocene, *i.e.*, to the Upper Siwalik.[145]

Hazara.—Recent gravels fill the valleys of Hazara, such as the Haripur plain, the Dore valley, the Abbottabad plain and the Mansehra plain, often to a depth which must exceed 300 feet.[146]

Certain Pleistocene and Recent deposits of the Himalaya.—The Recent and sub-Recent deposits in the Himalaya are represented by lacustrine sediments, moraines, talus accumulations and, more conspicuously, by the river gravels abundantly developed in nearly every valley, as well as along the outer foot of the range. These will be referred to incidentally in the chapter devoted to the Himalayan range, but there are three larger expanses of such deposits in Kashmir, Hundes and Nepal which being extensive enough to be depicted on the accompanying geological map, merit a description of their principal characteristics.

The Karewahs of Kashmir.—Forming part of the upper Jhelum valley, the alluvial basin of Kashmir has a length of about 84 miles and a breadth of some 20 to 25 miles, and lies at an altitude of 5,200-5,500 feet, separating the Pir Panjal on the southwest from the Great Himalaya on the northeast; it has an area of at least 2,000 square miles. It is occupied partly by low-lying alluvial deposits not much raised above the level of the Jhelum river, but principally by older beds exposed in elevated plateaux or terraces on the left bank of the Jhelum along the southwestern border of the younger alluvial plain, and elsewhere projecting through the latter as islands. These plateaux are known by the Kashmiri term *Karewahs*, a name which has been adopted for the deposits of which they are built. The maximum thickness of the beds has been estimated at 4,500 feet by Middlemiss who found patches of them on the northeastern slopes of the Pir Panjal between 11,000 and 12,000 feet above the sea, and suggests that they may at one time have swept up in the form of a great arch over the crest of this range. If this be correct, the Karewahs can have no relation to any present valley system or lake basin.[147]

In the more central part of the valley the deposits, which are freely dissected by streams draining from the Pir Panjal, consist of fine, soft sands, clays and loams, of a bright ochre tint.[148] Many of the clays are varved, some are carbonaceous, and among the beds are layers of impure lignite probably in disconnected basins; beds of this low-grade fuel from 2½ to 6 or 8 feet thick, occur not far from Srinagar. The topmost layer is an ancient soil of loess loam. All this loosely coherent sediment yields to erosion in a succession of small graded landslips, flowing forward, as it were, like a glacier or

[145] Mem. Connect. Acad., Vol. 8, Art. 1, p. 1 (1935).
[146] C. S. Middlemiss, Mem. 26, 44 (1896).
[147] Rec. 55, 243 (1923).
[148] C. S. Middlemiss, Rec. 41, 120 (1911).

mud-flow, having crevasses and similar features; the small lake of Nilnag has been formed by ancient slips of this kind. Away from the centre, sand and shingle play a more prominent part in the make-up of the deposits.

In the centre of the valley the beds are not far from horizontal. At Nilnag there is a dip of about 10° to the northeast, which increases up the slope of the Pir Panjal south-westwards to a monotonously regular dip of 18-19°; this, however, is interrupted by a small but distinct monoclinal fold showing dips up to 40° and occurring in soft loam, sands, brown sandstone and conglomerate beds, with occasional *kankar* and other minor puckers have been noted. Southwest of the monoclinal fold, the dip quickly reverts to its normal northeasterly direction and gentle character, but the slopes are thick with soil and forest and exposures infrequent. Between Frasnag and Ludar Marg there is a break in the Karewah deposits occupied by an out-crop of Triassic limestone. In the neighbourhood of Ludar Marg, however, Karewahs are to be observed again, underlying old morainic material and crop out in small patches higher up still. Thus the formation lies on the northeastern slope of the Pir Panjal, most of it beneath younger glacial deposits and occasionally disturbed by slight flexuring.

Lydekker divided the Karewahs into a lower division of tilted beds, corresponding probably to some portion of the Upper Siwalik sequence, and an upper division of more or less horizontal and younger beds. Probably all but the uppermost 1,000 feet belongs to the older division.

A few fossils, most of them vegetable in character, have been found. From the Lower Karewahs of the Ningal *Nala* near Gulmarg, at an altitude of some 9,800 feet, come some fish remains referred by Hora to the genera *Oreinus* and *Schizothorax*;[149] some of the scales are those of a fish closely allied to *Schizothorax curvifrons*, a form now living in the Kashmir valley, while a pharyngeal tooth is said to resemble that of *Orenus sinuatus* (Heckel). From the same stream course at an elevation of about 9,500 feet, Dr. Coulson has collected numerous plant remains.[150] From the Lower Karewahs de Terra records *Equus*, *Elephas* aff. *namadicus*, *Bos*, *Sus*, *Rhinoceros*, *Cervus*, *Felis* and *Sivatherium*, and some fish and bird bones.[151] From some of the shaly lignite and clay of the Lower Karewahs R. P. Wodehouse has identified pollen grains of *Cedrus*, *Pinus*, *Abies* and a few *Picea*, some grasses, *Corylus*, *Alnus* and *Betula*, *Juglans*, *Ulmus*, *Persicaria* (low herbs, some of them possibly aquatic), a chenopod, and. the composite, *Artemisia*.[152] All other organic remains so far collected appear to come from the upper Karewahs. Some *Planorbis* and a few leaves have been collected near Nilnag, and the following fresh-water mollusca, probably from almost the same locality, have been

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[149] Rec. 72, 178 (1938).

[150] Gen. Rep. Rec. 73, 90 (1939).

[151] Mem. Connect. Acad., Vol. 8, Art. 1, 14, (1934).

[152] Mem. Connect, Acad. Vol., 9, Art. 1, 5.

identified by B. Prasad:[153] *Corbicula* sp., *Lamellidens* sp., *Bensonia* sp., *Bithynia tentaculata* (Linn.), var. *kashmirensis* Nevill, *Gyraulus pankongenis* (Vevill) v. Martens, *G. convexiusculus* (Hutton), *Indoplanorbis exustus* (Desh.), *Succinea indica* Pfeiffer, and *Ena* (*Subzebrinus*) *rufistrigata* (Benson).

From Ludar Marg Middlemiss collected some very fragile but well preserved leaves, all belonging to living genera. By far the most numerous impression is that of an oak close to *Quercus glauca* Thunb.; there are a few examples of *Alnus* and *Cinnamonum*—one of the latter very like *C. tamala* F. Nees—one leaf of Box (*Buxus sempervireus* Linn.) and another very like *Jasminum*. The interesting point of this flora, as Middlemiss demonstrates, is the fact that it indicates a prevailing oak forest such as is found today at altitudes of 4,000 or 5,000 feet. Neither oak[154] nor box grows in the Kashmir valley or on its mountain sides today; *Alnus nitida*, Endl. is common by the sides of streams at 7,000 feet, but the present forest flora at the altitudes attained by these plant-bearing Karewahs is composed of fir, pine, spruce and birch. The conclusion follows that at the time the Karewahs were being deposited, the Pir Panjal could not have attained much more than half its present height.[155] Since that time, as the comparatively undisturbed state of the Karewah deposits shows, this mountain range has risen quietly with no appreciable buckling along its northeasterly flank to its present altitude. Among the specimens collected near Gulmarg by the Yale Expedition, S. K. Mukerji has recognised forest trees and shrubs such as the oak, willow, poplar, alder, barberry, rose, rhododendron, cinnamon, holly and box, and also several aquatic plants, notably the waternut or *singhara* (Trapa), *Vallisneria*, and some Charophyta or stoneworts.[156] The land plants are most of them represented by species now living on lower slopes, between 5,000 and 9,000 feet; a few like the rose, have a wide range in altitude, while others grow near the upper limit of tree vegetation. The aquatic plants mentioned above still flourish in the Wular, Dal and Manasbal lakes, or in the sluggish backwaters of the Jhelum, several thousand feet, as B. Sahni points out, lower than the heights at which their fossil remains have been found in the Pir Panjal; so far as is known they are not to be found in any of the numerous tarns and streams on the higher slopes of the range, where the water is either too encumbered with rushes, or frozen for too long a period in the year. The pollen identified from Upper Karewah sediments belongs to the following genera: *Pinus, Cedrus, Abies, Picea*, a cupressine *Ephedra* (a plant with a xerophytic habit), grasses, *Salix, Betula, Carpinus, Corylus, Alnus, Jugans*, a chenopod, and *Artemisia*. According to Wodehouse, the pollen collected from the Karewahs provides no indication that the climate

[153] Rec. 56, 356 (1924); Ibid., 72, 24 (1938).

[154] The oak is plentiful in the neighbourhood of Murree which is some 7,200 feet above sea-level.

[155] Rec. 44, 38 (1914).

[156] De Terra, Mem. Connect. Acad., Vol. 9, Art. 1, p. 1 (1934); B. Sahni, Current Sci., Vol. 5, 12 (1936).

of either the Lower or Upper Karewah epoch differed from that pertaining to Lake Manasbal today. Palaeoliths have been found in the Upper Karewhas.

Resting along its northern margin on glacially smoothed mountain spurs, the Karewah formation is a mixture of lacustrine and fluviatile sediments and includes in addition deposits of glacial till and wind-blown loess. The frequent alternations of gravel and sand represent deposits either laid down in the ordinary way by a river in a broad alluvial valley between its permanent banks, or brought into a lake by a river feeding it. The fragmentary state of the fossil shells produces the impression that lacustrine conditions were not more thoroughly developed at that time than they are today.[157] The thin layers of lignite point to marshy conditions in certain parts of the valley at certain times, but the absence of laminated shales, the limited extent of bedding when sufficiently distinct to be recognisable as such, and the common occurrence of coarse sand, are more characteristic of river deposits. It is not necessary to suppose that the whole of the Kashmir basin was ever occupied by a single vast lake. At the present day lacustrine deposits are being formed on the northern limit of the valley where deficiency of deposition has left hollows in which water has accumulated, and it is probable that throughout the latter part of the Karewah period conditions were much the same as they are today, and that minor areas of true lacustrine deposition existed side-by-side with other areas over which sub-aerial accumulation of sediment was in progress. It would be noted that the flood-plain of the Jhelum in the Kashmir basin is today readily inundated by a heavy fall of rain. The Wular and Dal Lakes are scarcely more than permanently inundated covers of the great Kashmir plain. Peat with over 37 per cent. of carbon is reported to have been found in the vicinity of the Wular Lake.[158]

Deposits equivalent to the Karewahs and characterised by frequent earth pillars have been noted in Spiti.[159]

Old lake deposits forming a wonderful series of 20 terraces or more around the Tang Rao Tso between Shentsa dzong and Wom-po in Tibet, are said to be comparable with the Karewahs.[160]

The northeastern slopes of the Pir Panjal are characterised by old and well preserved stranded moraines and morainic material, uniformly covered with grass, a few scanty birch trees and dense clumps of stunted juniper. These glacial deposits are younger than the Karewahs, and in a few places can be seen resting upon outlying plant-bearing patches of the latter. The lower-lying portions of this material are partly re-sorted but it is less sorted higher up. Between 12,000 and 11,000 feet it begins to debouch from numerous higher valleys in pairs of regular lateral moraines 500 feet thick;[161] these points of emergence are 2,000 feet below and several miles

[157] Rec. 32, 152 (1905).
[158] R. Lydekker. Mem. 22, 332 (1883).
[159] F. Stoliczka, Mem. 5, 119 (1865).
[160] A. L. Coulson, Rec. 67, 336 (1933).
[161] C. S. Middlemiss, Rec. 41, 121 (1911).

distant from the present-day belt of live ice and active moraines. This glacial material, partly redistributed, tails out in this way downstream to levels as low as 7,000 feet altitude, while a few very large erratics of Panjal Trap, 54 feet across, are found as low as 6,500 feet, as for instance at Arigam village where they repose on an extremely gentle slope. The moraine rock consists largely of Panjal Trap, sometimes in enormous angular blocks.

The Valley of Nepal.—The only other valley at all comparable with the alluvial basin of Kashmir is that of Nepal[162] which, like Kashmir, is a longitudinal valley lying along the general strike of the strata. While, however, the open oval area of Kashmir coincides approximately with the elliptical synclinal depression of the calcareous upper Palaeozoic strata, Nepal is rather a group of confluent valleys with high dividing spurs. There is no remnant of a lake but other features are alike, and the deposits in Nepal, covering an area of 125 square miles, correspond very closely with those of Kashmir. An extensive upland area, known as *tanr* land, corresponds to the karewah of Kashmir and to the *bhangar* of the Gangetic plains (*see* p. 1932); it is the surface of the old deposits, though no doubt considerably modified by waste in the central parts and by rain-wash accumulations near the hills. The streams flow at a depth of from 50 to 500 feet below this surface, according to position, and, as in Kashmir, have by their overflow carved out lower-lying valleys of younger alluvium, known as *kholas* and corresponding to the *khadar* lands of the plains. Beds of serviceable peat, much used for brick and lime burning, occur at various levels in the valley deposits. There is also a blue clay, extensively employed for top-dressing the fields; its fertilising virtue seems to be due to the phosphate of iron (vivianite) freely scattered through it in blue specks. No fossils have as yet been found in any of these deposits.

The Upper Indus Valley.—Pleistocene and Recent screes and alluvium cover a large area in the Indus valley between Chilas and Gilgit, and are such as characterise a desert region[163] subjected to a fitful and scanty rain-fall. Long stretches of the valley are occupied by wide-spreading, gently sloping talus-fans and wind-blown sand, supported on gravel terraces which reach to heights of 1,500 feet above the stream beds; between Gurikot and Astor, Wadia has counted as many as five of such terraces, one above the other. Lacustrine deposits are reported near Jullipur and Bunji, formed by landslips and glacial barriers in late historical times. The alluvial sediments of this region are slightly auriferous, and goldwashing is one of the chief industries of a thinly scattered population.

The third terrace above the Suru river at Kargil has yielded a Palaeolithic flake of greenish black trap.[164]

Hundes.—The Pleistocene deposits of Hundes occupy an area, some 120 miles long by 15 to 60 miles broad, in the upper valley of

[162] Rec. 8, 93 (1875).

[163] D. N. Wadia, Rec. 66, 225 (1932).

[164] De Terra, Mem. Connect. Acad., 8, Art. 1, 8.

the Sutlej, which now flows in a deep and narrow gorge, not much less than 3,000 feet deep, excavated in the horizontal silts laid down by itself at an earlier period of its history.

Our knowledge of these beds is largely dependent on a description by the two brothers, Richard and Henry Strachey.[165] In the central portion of the valley, the cliffs throughout their height exhibit a fine homogeneous clay containing but little gravel. It is therefore possible that some of these deposits were formed in local accumulations of water or lakes ; the bulk of the beds, however, are probably of fluviatile origin.

The gravels have yielded mammalian remains, probably all of them belonging to living genera.[166] Of these *Bos*, *Ovis* (?), *Capra* and *Equus* are genera still living in the highlands of Tibet. *Hyaena,* whose determination is open to question, is not now known in Tibet, though there is no reason why it should not formerly have ranged into such high altitudes. At first sight, the remains of *Rhinoceros* would appear to indicate a warmer climate and a lower altitude than those in which they now occur ; it is, however, not impossible for a rhinoceros, especially one of small size, to have lived on the bushes which grow in the neighbourhood of many of the Tibetan rivers. In any case the doubtful evidence afforded by this genus is more than outweighed by that of a skull fragment figured by Royle ("Illustrations of the Botany, etc. of the Himalaya Mountains". 4° London, 1839, Pl. III, figure 1) : the original specimen is in the south Kensington Museum, and agrees so closely with *Pantholops hodgsoni* that there can be little doubt of at least generic identity. *Pantholops* is a genus peculiar to the most elevated and coldest portions of Tibet, and it is consequently more probable that the sub-Recent deposits of Hundes were formed at or near the elevation at which they are found today than that they accumulated at a much lower level and were subsequently raised to their present elevation. The latter suggestion was made when the beds were thought to be of Tertiary age, but there is no indisputable evidence in favour of a Tertiary age, and the undisturbed horizontality of the beds, which themselves lie on tilted Pliocene sandstones is against such a view and against the supposition of any extensive elevatory movement except by prolonged steady upthrusting ; any plicatory movement would almost certainly have produced some appreciable tilt in the beds.

Alluvial deposits of the Himalayan foot-hills.—The alluvial deposits of the Ganges and Indus form the subject of a special chapter, and a few cursory remarks are all that are necessary concerning the small deposits of gravel and alluvium within the Himalayan foot-hills. Along this fringe of the mountain banks of coarse gravel and torrent-boulders, generally mixed with ferruginous sand or clay, line many of the larger streams and rivers and cover extensive portions of the longitudinal valleys or *duns* which separate these marginal ranges

[165] Q. J. G. S., 7, 292 (1851) ; C. L. Griesbach. Mem. 23, (1891) ; and R. Lydekkar. Rec. 14, 178, (1881).

[166] The determination of *Hippotherium* by Waterhouse is questionable, the material being insufficient.

from each other and from the higher ground of the Lesser Himalaya. Where the streams carry much lime in solution, the gravel and sandy clays are interstratified with beds of calcareous tufa, large weathered blocks of which obstruct the stream beds. In places this tufa has been carved into a series of steps or falls, some of them as much as 50 feet in height.[167] Impressions of land shells and plants are frequent in the tufa.

The large gravel fans along the base of the Himalayan foot-hills are described in a later chapter, and allusions will be found under the heading of Himalaya to alluvial deposits within the mountains themselves. As an easily accessible example of such accumulations, attention may be drawn to a considerable stretch of river detritus in the stream which drains the southern slope of the ridge between Prospect Hill and Jutogh. This material consists of a typical *melange* of more or less angular fragments, varying in size from fine gravel to rock masses several feet across. The fact that the deposit possesses distinct stratification proves it to have been sorted by water action, and not to be undistributed moraine. The angular nature of the larger constituents of the debris witness to the short distance they have travelled.

River gravels of Assam.—Pleistocene river gravel terraces are recorded by Maclaren along the foot-hills of the Himalaya of Upper Assam and in the upper Dihing valley. In the Dapha, the principal tributary of the Dihing, there are three terraces, one above the other, the surface of the highest and oldest being 1,000 feet above the level of the valley; the terraces are composed of the same rocks as are now found in the bed of the valley.[168] A terrace of the same kind and 150 feet high at Mishmi Ghat, where the Brahmaputra leaves the foot-hills, shows a rude but distinct stratification of its gravels. Many other horizontal undisturbed terraces of this nature are seen in various parts of the Upper Assam valley the gravel composing them consisting of pebbles and boulders of the same rocks as those found in the present bed of the Brahmaputra.[169] In the Bhareli (Bhoroli) section of the Aka Hills north of Tezpur, the first hills are occupied by unstratified Pleistocene drift of well rounded boulders and pebbles derived from the hills to the north; of the material composing these pebbles gneiss and granite predominate, while quartzite and hard sandstone from the Damudas and Tertiaries are common.

A large accumulation of boulders near the Kohima road in the Naga Hills district reaches heights of over 1,500 feet above sea-level.[170] Plateau gravels also occur in Cachar, some of them rising to 350 feet above the alluvial level.

The "pungs" of Assam.—Mention may be made of the so-called *pungs* or "salt-licks" which are a feature of the Assamese jungles. These vary from patches of bare moist soil or rock with a saline efflorescence, to small swamps or pools of brackish water which

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[167] C. S. Middlemiss, Mem. 24, 78 (1890).
[168] Rec. 19, 114 (1886).
[169] J. M. Maclaren, Rec. 31, 195 (1904).
[170] P. Evans., Trans. Min. Geol. Inst. Ind., Vol. 27, 240 (1932).

exudes slowly from the ground. When it issues more rapidly, the term, "salt spring" is often substituted for *pung* but the two are practically synonymous. These *pungs* or salt springs are often characterised by emanations of hydrocarbon gas or a seepage of petroleum, when the term "salse" is equally applicable. The comparative openness of the ground and freedom from dense jungle in these *pungs,* which are usually quite small areas, is due partly to the saltness of the soil and partly to the constant coming and going of wild animals. The latter are said to come for the purpose of licking the salt, but the writer has suggested that the chief attraction in such a place, apart from its openness, may be the efficacy of salt in removing leeches without causing unnecessary bleeding from the bite. The Assam jungles are infested with leeches and suffering beasts could easily rid themselves of these pests by rolling in or splashing themselves with the salt mud. The muddy ground is frequently covered with the tracks and wallowings of wild elephant, barking deer, sambhar, wild pig, etc. True *pungs* are very rarely if ever found on Tipam beds, but are especially characteristics of the Coal Measures and are plentiful also on the Disangs.[171]

In the hills along the eastern confines of India are some rock basins occupied by alluvial deposits, the best known of which is that of Manipur, sometimes spoken of as Lake Logtak (Longtak).[172] About 50 miles long by 20 broad, of an irregular shape, and with many small hills rising like islands from this alluvial plain, it is not surprising that it should be regarded as a filled-in lake. There are, however, no real reasons for supposing that any large proportion of the valley was ever occupied by deep water. There are, for instance, no terraces round it such as would have resulted from successive lowering of the outlet during the long period of deposition. The deposits are all of ordinary alluvial type, and the courses of the streams show that the present surface is the result of the slow and gradual formation under sub-aerial conditions of an alluvial plain. The elevation of the surrounding hills is, geologically speaking, of comparatively recent occurrence, the bulk of the movement dating probably from the latter portion of the Tertiary period. The formation of the Manipur rock basin followed but was probably a gradual process; the active erosion of the neighbouring hills, assisted by an abundant rainfall, caused it to be filled up as fast as it was formed, with the exception, perhaps, of insignificant areas that were temporarily occupied by shallow lakes.

In the hills of Assam and western Burma examples of transverse drainage are not wanting but, owing to a heavier rainfall and denser vegetation, the alternation of deep narrow gorges with broad open valleys seen in dry regions such as western Baluchistan is not so abrupt. The chemical action of the humic acids developed in the jungle-clad soil has smoothed off the steepness of the gorge walls, while the vegetation has protected the softer clays from being so easily washed away.

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[171] E. H. Pascoe, Mem. 40, 317 (1914).
[172] R. D. Oldham, Mem. 19, 237 (1883).

III. BURMA

The upper waters of the Chindwin river drain a number of alluvium-filled valleys, the largest of which, on the upper part of the Chindwin itself, is known as the Hukawng valley; in the hills to the west are the Kubo valley and other valleys to the south of it. About 90 miles northeast of the Hukawng plain is that of Putao drained by feeders of the Mali Kha. Further south it is possible to distinguish post-Tertiary deposits of two separate periods.

THE PLATEAU GRAVEL AND PLATEAU RED EARTH.

Lower Burma.—Along the margin of the alluvial deposits of the Irrawaddy and Sittang, there is a broad but interrupted belt of undulating ground, clearly distinguishable from the flat plains of younger alluvium near the rivers, both by the greater inequality of its surface and by its more sandy character. This tract is locally known as "*In-daing*" or the country of the "In" tree (*Dipterocarpus grandiflora*), but the same name is also applied to the very similar sandy tracts occupied by the Irrawadian formation, so that the popular distinction is not a precise geological one. In Henzada this plateau is much covered with a forest of *In*, a selective association in marked contrast to surfaces of shale which are clothed with bamboo and teak.[173] The *In-daing* tract is composed chiefly of gravel, derived in a large measure from the neighbouring hills, but partly from distant rocks. A portion of the deposits, like the *bhabar* along the edge of the Ganges valley, may be simply the detritus washed from the surface of the hills by rain and small streams to form a slope at the base of the range, but in Pegu, with its heavy rainfall, this slope is inconsiderable, and the greater portion of the alluvial gravels is made up of stream and river deposits. Similar beds of sand and gravel are found in many places underlying the argillaceous deposits of the Irrawaddy delta, and are evidently of more ancient origin than the latter.

Besides the fringe of variable width formed by the gravels along the edge of the older rocks, large isolated tracts of the same older alluvial deposits are found in places in the more central parts of the delta, rising occasionally to a considerable height above the flat surrounding country. One such tract, 20 miles long by 10 miles broad, occurs south of Bassein, and another of about the same dimensions lies southwest of Rangoon. These areas may be ancient *bhangar* deposits (see pp. 1993-96).

Upper Burma.—In Upper Burma these older alluvial deposits are represented by what has been called the Plateau Gravel, passing laterally into the Plateau Red Earth. These deposits for the most part lie with an unconformity—sometimes with a marked unconformity—upon the eroded Irrawadian or Pegu beds. Like the Irrawadian they are almost certainly of fluviatile origin, and belong to the successor of the river responsible for the Irrawadian silts. It is

[173] M. Stuart, Rec. 41, 252 (1911).

not improbable that places will be found where deposition has been continuous from Irrawadian to Plateau Gravel times, since the river can never have ceased to flow and is not likely to have ceased everywhere to deposit silt, but the pronounced hiatus between the Irrawadian and the Plateau Gravel, seen in so many sections along the present Irrawaddy river banks and elsewhere, indicates some important and rapid change in the life history of the river. It has been suggested that the original Irrawaddy and the Tsangpo of Tibet were at one time united by way of the Chindwin to form a single river, and that the upper half of this great waterway was captured by the forerunner of the Brahmaputra. It is further suggested that this capture of the Tsangpo and the consequent great reduction in size of the Irrawaddy, took place at the end of the Irrawadian sediments and the Plateau beds. The thick sequence of the Irrawadian would thus represent the silts of the Tsangpo-Chindwin-Irrawaddy river, while the Plateau beds would represent the much smaller and less prolonged drainage of the present Irrawaddy and Chindwin.

The Plateau Gravel varies very much in coarseness and consists typically of pebbles loosely aggregated in a deep red ferruginous sand; a common size for the pebbles is between one and two inches, but they range up to 18 inches across. Boulders from 6 to 8 feet high are found scattered over the Pakokku district and are probably the result of unusual floods. Pieces of rolled fossil wood and sometimes rolled fragments of bone are to be found; among the latter T. Oldham records the broken femur of an elephant and fragmentary tortoise bones.[174] The pebbles are identical with many of those found in the Irrawadian conglomerates and like them are mostly of quartz. In Lower Burma Theobald found many pebbles of very hard siliceous schist and a considerable amount of rolled fossil wood; one pebble was of a hard trap rock.[175] In the Yaw river gravel beds are found at high levels, sometimes as much as 300 feet above the river. The distribution of the Plateau Gravel has never been properly investigated. It is well exposed in portions of the riverine tract in Magwe, Minbu, Myingyan, Pakokku and Sagaing, and has been recognised further north in the Lower Chindwin and Shwebo districts.[176] In some parts of the Lower Chindwin district the Plateau Gravel is rich in round, hollow, ferruginous concretions which appear to have been worked at no very distant date for iron by local villagers.[177]

Some of the Plateau Gravel pebbles may be derived directly from the old pre-Irrawadian rocks which now crop out along the flanks of the Irrawadian tract. This is more likely to be the case in the neighbourhood of these flanks, and examples in Pakokku have been quoted where some of the pebbles are composed of schist similar to that which is so common in the neighbouring exposures of the Axial formation around Kanpetlet.[178] There is little doubt, however,

[174] Yule, Mission to the court of Ava; Append. p 312 (1855).
[175] W. Theobald, Mem. 10, Art. 2, 53 (1873).
[176] Gen. Rep. Rec. 61, 104 (1928); Gen. Rep. Rec. 62, 125 (1929).
[177] Gen. Rep. Rec. 61, 63 (1928).
[178] G. de P. Cotter, Mem. 72, 111 (1938).

that the bulk of the pebbles, especially those in the more central portions of the Plateau Gravel tract, come from disintegrated conglomerates of the Irrawadian; rolled pieces of Irrawadian conglomerate, including ferruginous matrix as well as pebbles, have been found by the writer in the vicinity of Yenangyaung.[179] Chipped flints have been picked up from the surface of the plateau near Yenangyaung, all of them probably belonging to the Plateau Gravel.[180] Vertebrate remains are occasionally found in the Plateau Gravel, but to what extent these are rolled fragments derived from the Irrawadian conglomerates, or are indigenous to the Gravel has never been properly investigated. Amber from Mandalay was found by Professor Cockerel of Colorado to contain well preserved insects differing from those identified in the Hukawng valley amber and not older than Pleistocene; among them is a small bee which shows no appreciable differences from the common living *Trigona* (*Melipona*) *laeviceps* Smith. The latter builds in the hollows of trees and in rock crevices, lining the interior surface of its nest with a massive resinous substance known as *dammar*. This, it is thought, is derived from the oil and resin of *Dipterocarpus*, the family which has furnished the great bulk of the fossil wood found in both the Irrawadian and Plateau Gravel. It is possible, therefore, as Murray Stuart points out,[181] that the Pleistocene amber of Mandalay as well as the older amber of the Yukawng valley may be merely fossil *dammar*.

The Plateau Gravel when traced laterally becomes finer, the pebbles becoming smaller and the deposit as a whole replaced by a red, ferruginous, clayey sand, the Plateau Red Earth. To what extent this change is due to an actual passage of one deposit into the other it is difficult to say, for both are very thin. The average thickness of the Plateau Gravel in the central area may be put down at 5-10 feet, but it may be less or considerably more; the Plateau Red Earth averages about 3 or 4 feet, is often reduced to 1 foot and sometimes swells to 30 or 40 feet in low-lying situations. Some of the Red Earth, therefore, probably represents the finer silts of the river which deposited the Plateau Gravel—silts which have become ferruginised by a process for which Theobald used the term, "laterosis". On the other hand, other portions of the Red Earth appear to be nothing more than ferruginised soil-caps formed by laterosis of the superficial layer of the Irrawadian; such caps frequently show irregular angular or serrated junctions with the underlying Tertiary beds. The Plateau silts, like the Gravels, must lie unconformably upon the Irrawadian, but the ferruginisation which has affected the surface of Plateau and Irrawadian beds alike makes it difficult or impossible to define this contact. Plateau Red Earth is a term, therefore, which has been applied to the ferruginised river silts of both Irrawadian and post-Irrawadian age. The colour of the Plateau Red Earth varies from a bright vermilion to a deep chocolate, but is most

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[179] Mem. 40, 49 (1912), see also Gen. Rep. Rec. 62, 125 (1929).
[180] E. H. Pascoe. Mem. 40, 66 (1912).
[181] Journ. Inst. Petrol Techn. 11, No. 52, 480 (1925).

commonly a brick-red. *Kankar* occurs in it locally but there are no fossils. For the most part it is unstratified, but here and there are seen examples of sorting action in the form of thin layers, not more than an inch thick and extending perhaps for two or three feet, of more clayey material, coarser sand, or fine gravel; this may well be the effect of rain-wash.

The topography of the Plateau beds is a rolling tableland, much dissected in places by steep winding ravines, each with its complicated system of tributaries. In Central Burma the height of this plateau above the present level of the Irrawaddy is between 400 and 500 feet. By far the bulk of the Plateau Gravel and Plateau Red Earth varies little from a horizontal position. There are, however, occasional exceptions; one of these appears to occur opposite Mandalay, where *Elephas antiquus* (*namadicus*) has been obtained from some beds which are presumably of Pleistocene age though described as showing marked disturbance.[182]

Red earth derived from the Plateau Limestone.—A deposit very similar to the Plateau Red Earth, but occurring on a higher lying plateau, is the mantle of red clay, comparable to the "terra rossa" of Istria and Dalmatia and covering everywhere the surface of the Plateau Limestone whose outcrop occupies such a large area in the Shan States. This surface deposit has already been mentioned and has originated from the Plateau Limestone itself by the weathering out therefrom of insoluble matter and interstratified bands of shale and clay. It is a stiff tenacious clay with little or no sandy matter, often full of pisolitic nodules of iron oxides ranging in size from small shot upwards. This residual clay appears to have undergone an incomplete form of lateritisation, the final product differing from true laterite in the absence of siliceous matter, an ingredient which is also wanting in the limestone. In some places the iron oxides are present in commercial amounts and have been exploited and used as a flux in the smelting of the lead and silver ores of Bawdwin. The presence of this plateau clay with its iron contents can only be accounted for on the assumption of erosion on an enormous scale since the latter half of the Mesozoic era when the Shan plateau emerged from the sea, for the limestone or dolomite of the plateau contains on an average no more than 1·09 per cent. of insoluble residue and not more than 0·76 per cent. of the oxides of aluminium and iron.[183] At one time, as Coggin Brown notes, the iron contents must have been equally distributed through the red clay, and their concentration into irregular bodies at the base of the clay must be due to subsequent processes. For some unknown reason, ores in the lower parts of the plateau as well as the pisolites which frequently occur in the upper layers of the red earth, are often highly aluminous.[184]

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[182] Gen. Rep. Rec. 43, 13 (1913).
[183] T. H. D. La Touche, Mem. 39, pt. 2, 188 (1913).
[184] Gen. Rep. Rec. 61, 61 (1928).

At Thin-nge, between Mandalay and Maymyo, the ore occurs in rounded grains, pebbles and masses, ranging up to boulders several feet in diameter and weighing many tons, loosely embedded in the clay.[185] These segregated masses usually exhibit a light brown polish due possibly to a thin skin of limonite; inside, the ore is black or brownish black with numerous irregular reddish patches, consisting apparently of a mixture of limonite and hematite with perhaps some colloidal hydroxides. Similar ores have been utilised in the neighbourhood of Wetwin and Padaukpin. The deposit at Manmaklang consists largely of limonite and is used for flux purposes, but the iron is less concentrated; here the ores have formed, according to Coggin Brown, as a result of the downward percolation, through an exceedingly brecciated variety of the Plateau Limestone, of iron-bearing waters of meteoric origin.[186] At Kunghka the ore occurs actually in a fault in the Pangyun beds (Cambrian or Ordovician), but is believed by E. C. Bloomfield to be derived from Plateau Limestone which formerly overlay these beds and to have found its present resting place by the infiltration of iron-bearing solutions into the fault detritus. The ore-body is made up of lenticles and veins of solid hematite in a soft matrix of limonite; in the matrix are numerous platy crystals of specular hematite and small nodules and veins of barytes.[187] Lenticles of sandstone are also present. Close to the Kunghka occurrence is a detrital deposit of similar nature lying on the surface.

Three large occurrences of iron ore have been reported in the Jade Mines area of the Myitkyina district, two near Lamong and the third between Nammaw and Kattang. The ore occurs generally in the form of boulders scattered through a rich red earth, but in places forms a hard crust entirely devoid of vegetation.[188] The bulk of the material is made up of earthy and crystalline hematite and limonite. This ferruginous red soil lies as a thick mantle particularly on the periodotites and serpentines of the Jade Mines rock assemblage, with which basic igneous rocks, the iron ore appears to be especially associated. Like those found on the Plateau Limestone, these ores are probably residual and derived from a concentration of the iron contents of the underlying igneous rocks. The deposits occupy the tops of plateaux 2,000 feet high. Since boulders of iron ore are included in the Uru conglomerate, its formation must have been in progress in late Tertiary times.

Type of drainage on the Shan Plateau.—On the Shan Plateau proper, where limestone is the prevailing country rock, denudation proceeds, as La Touche remarks,[189] more or less evenly over the whole area, much of it being subterranean and due to solution of the limestone. The insoluble constituents of the Plateau Limestone remain on the surface in the form of a thick mantle of red clay, through which

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[185] J. Coggin Brown. Rec. 47, 138 (1916).
[186] Gen. Rep. Rec. 61, 58 (1928).
[187] E. L. G. Clegg, Rec. 54, 433 (1922).
[188] Gen. Rep. Rec. 62, 54 (1929).
[189] Mem. 39, pt. 2, 20 (1913).

the solid rock appears only at intervals. "The smaller valleys are broad and shallow, with gently sloping sides, and are usually traversed by sluggish streams, often bordered by morasses. It is only where several streams have united and have sufficient power to cut through the covering of clay, that the rocks beneath are exposed, and then, if the conditions are otherwise favourable, a narrow gorge, bordered by precipitous cliffs of limestone, and choked with masses of rock fallen from either side, is formed. The deposition of travertine or calcareous tufa in all the streams is very rapid. In some cases it raises the level of the stream-bed to such an extent in the shallower valleys, that the water breaks away to one side or the other, and a network of anastomosing channels is formed, resembling that usually associated with deltaic conditions". A conspicuous example of this feature is seen in the broad valley in which lies the town of Hsum-Hsai (Thonze), where, on the cart-road and railway, an extraordinary number of culverts and bridges have had to be constructed; all these streams eventually drain into the single channel of the Hpawng-aw which flows into the Nam Tu through a narrow limestone gorge.

In common with all limestone plateaux, the Shan Plateau is characterised by the occurrence, often over large areas, of depressions in the surface, where the drainage passes underground. In size these depressions vary greatly, from mere pipes of a few feet in diameter, through "swallow-holes" and funnel-shaped "punch-bowls" to enclosed valleys several miles in length and breadth. The commonest of these are the punch-bowls, the smaller of which are found in greatest number along the crests of limestone scarps, where the water finds an easy outlet on the face of the cliffs. The abundance of these depressions in the Northern Shan States in the opinion of La Touche, is a result of the intensely crushed condition of the limestone; the latter being in too shattered a condition to support its own weight, the caverns ordinarily found in a limestone tract are not formed and are replaced by areas of local and constant subsidence. In the Southern Shan States and Lower Burma, where less crushed, non-dolomitic types of the Plateau Limestone are more fully developed, caverns are more frequent. The larger depressions or "cauldron valleys" (*Kesselthaler*) are found along the flanks of the ranges to the east of the plateau, where the limestone has been thrown into folds together with the underlying rocks. Such valleys vary in size from mere ravines a few hundred yards across to a valley like that in which the village of Lukhhai, on the south side of the range east of Lashio, is situated; this valley is about 4 miles in length and 2½ miles in breadth, and contains more than one subsidiary depression or swallow-hole within its area. In such valleys the stream that flows through them generally disappears abruptly beneath a vertical wall of limestone into the mouth of a small cave, but in other cases there is no visible outlet, the water soaking through the soil which fills the bottom of the hollow, the latter becoming a morass during the rainy season.

In places where the Plateau Limestone has been completely or almost completely removed by denudation, the drainage system

initiated by the limestone is often seen to have been superimposed upon the rocks beneath. In this way the main water channels of such a region may be at variance with and sometimes at right angles to the strike of these older rocks. Such impressed drainage is exemplified by that which obtains in the Bawlake State of Kerenni, where the main drainage is approximately at right angles to the trend of the older rock formations; some of the streams can be seen cutting across limestone ridges to which they were antecedent.[190]

The scenery of the Shan Plateau is typically one free from conspicuous features, except where a fault has depressed one portion of the surface relatively to that of another; in such a case a precipitous scarp of limestone may be left, extending in a direct line for many miles, whitened by an accumulation of travertine hanging in thick curtains from the cliffs or banked in some narrow picturesque gorge excavated by a river. La Touche describes the country as one of gentle declivities and rounded interlacing hillocks, covered as far as the eye can see, after the rainy season, with a dense matting of *kaing* or elephant grass, interspersed here and there with low scrub jungle or with park-like savannahs of scattered oak trees. The scenery is said to be not unlike parts of the English Downs or, having regard to the deep red colour of the soil, the rolling hills of Herefordshire.[191]

"**Sand Lodes**".—The so-called "sand lodes" of the Mawchi mines area in Bawlake have been described by Hobson,[192] who concludes that they have been produced by the rapid filling up of natural fissures or fault-planes or easily excavated quartz veins with more or less water-worn detritus. The detrital filling varies from clay, silt and fine sand to a gravel of frequently well-worn pebbles, some of them of considerable size. Within these restricted channels rock material has been intermittently stirred up and carried forward, and the localised grinding without violent impact has produced well-rounded pebbles of wolfram, a substance which by reason of its strong cleavage never produces pebbles as a result of ordinary open stream attrition but splits at once and very readily into tabular fragments of decreasing size. In some cases the material of the "lode" is comparatively unclassified and not very water-worn—an indication of sudden accumulation. A concentration of heavy material has occurred in these channels by a kind of natural elutriation, and the proportion of wolfram and cassiterite is often large enough to repay washing. Immediately over the sites of these "sand lodes" there is always a considerable accumulation of travertine.

Cave Deposits.—From a limestone cave on the east side of the Mogok valley have been obtained a number of fossil bones and teeth, including an ursoid animal, fragmentary jaws of pigs, deer and antelopes, and some teeth of a *Stegodon;* from the presence of the last, the remains are probably of Pleistocene age.[193] Another

[190] G. V. Hobson. Trans. Min. Geol. Ind., Vol. 36, 60 (1940).
[191] T. H. D. La Touche, Mem. 39, pt. 2, 21 (1913).
[192] Trans. Min. Geol. Inst. Ind., Vol. 36, 63-64 (1940).
[193] Gen. Rep. Rec. 61, 18-19 (1928).

cave in the neighbourhood of Mogok yielded the skull of a carnivore which A. S. Woodward has assigned to a new genus, *Aelureidopus*, and named *A. baconi*.[194] In another cave of this region was found the limb bone of a mammal about the size of an ox, worked by human agency;[195] in addition, this cave yielded a rhinoceros close to *Rhinoceros sumatrensis* and perhaps a variety thereof, a pig probably identical with the Indian wild pig *Sus cristatus*, a species of *Bos* indistinguishable from a living form, a species of deer about the size of the *sambhar*, *Cervus aristotelis* and a species of *Stegodon*. The last is differently mineralised and may be older than the other specimens; it may have been derived from an alluvial deposit.[196]

In the east side of Naungkwe Taung in Amherst district a cave is reported with a bone bed from a few inches to four feet thick, lying on a limestone floor and covered by a layer of stalagmite eight inches to several feet in thickness.[197] The bones, which include those of bear, pig, ox, deer and antelope, are plentiful but fragmentary, and occur in a matrix of reddish brown earth.

A small cave in the southern face of Lutshan Taung in the same district contains a number of stalactites hanging at 35° from the vertical, an anomaly due to the northward tilt of the limestone in which the cave is excavated since the formation of the stalactites; Leicester suggests that such a tilt may have been caused by comparatively recent slipping along old fault planes.[198]

Coal Basins and Lakes.—Lying upon those portions of the Shan plateau which surround the high ground culminating in the lofty peak of Loi Ling are some half-a-dozen old lake basins all of which occupy present river valleys; most of them have acquired some importance from the beds of lignitic coal they contain. The deposits in these basins may be of late Tertiary age, but La Touche is more in favour of a Pleistocene age in view of the low degree of consolidation and lack of disturbance; the seams of coal are, in fact, the most substantial members of the succession.[199]

One of the best known of these coalfields is that of Lashio in North Hsenwi. The Namyau runs along the southern boundary of this field, which is about 15 miles long and averages some 4 miles in breadth. The floor of this basin consists partly of Plateau Limestone and partly of Namyau Sandstone, and not only do the lake silts cross the boundary between these two old formations without interruption, but they traverse in the same way a large fault which is marked by a line of hot springs. The coal, which is found only along the southern border of the basin and appears to be confined to the lower portion of the silts, is a brown-black lignite carrying 17-20 per cent. of moisture; one of the outcrops is 25 feet thick, another measures

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[194] G. E. Pilgrim. Pal. Ind., New. Ser. 18, 48 (1932); E. H. Colbert, Amer. Mus. Nat. Hist., 74, Art. 6, 429 (1938).
[195] Gen. Rep. Rec. 65, 18 (1931).
[196] Gen. Rep. Rec. 65, 19 (1931).
[197] Gen. Rep. Rec. 63, 97 (1930).
[198] Gen. Rep. Rec. 63, 95 (1930).
[199] T. H. D. La Touche, Mem. 39, pt. 2, 310 (1913).

11 feet, and there are two or three smaller ones ;[200] from an economic point of view the lignite has been reported upon by C. H. Lander.[201] The rest of the beds consist of soft sandy silts and sand-rock with very subordinate pebble bands and an occasional layer of harder ferruginous sandstone which is indurated only near the surface as a result of the concentration of iron oxide. None of these silts is strong enough to form either a roof or a floor to a coal mine. The beds are little disturbed but show a gentle northerly dip where banked up against the older Palaeozoic limestone or Mesozoic sandstone.

A small patch of similar lake deposits is seen a little higher up the Namyau, but appears to be without coal.

Perhaps the most important of the basins, since it contains the most promising coal seams, is that of Namma, south of Lashio, in Southern Hsenwi, extending along the north bank of the Nam Pawng from its junction with the Namma and having an axis directed N.E.-S.W. It has about the same dimensions as Lashio but is for the most part covered with dense forest which hinders development. The lake silts, which are more varied in character than those of Lashio, lie upon the Plateau Limestone except for a short distance along their eastern edge where they are superimposed on some hard, purplish, thin-bedded, much jointed sandstones which are of doubtful age but rest apparently unconformably upon the Plateau Limestone. The beds consist of soft, yellowish clays with intercalated coal seams, soft, white or yellow sandstones and conglomerates; the yellowish clays are here predominant and the sandy silts subordinate. The principal seam of coal, 7-17 feet thick, is made up of a lustrous lignite of better quality than that found elsewhere in the Northern Shan States; here again the seams appear to be restricted to the basal portion of the beds. Some of the clay is a pure white kaolin. The pebbles and boulders in the conglomerate are made up of yellow quartz, quartzite and crystalline rocks, including a granite, derived from the hills to the east. The general dip averages about 20°. The clays have yielded the following fresh-water gastropods.[202]

Taia naticoides, an extremely variable living species, some specimens scarcely distinguishable from *T. theobaldi*,

Taia (Crassitaia) infracrassata Annand., a highly modified form, occurring in much greater abundance,

and at least five species of Hydrobiidae, three of them showing affinities with Chinese forms, *viz., Oncomelania fragilis* Annand., *O. conoidalis* Annand, *O.* sp., *Paraprososthenia minuta* Annand. and *Amnicola* sp.

Fox notes that fresh-water gastropods are found in the lignite itself as well as in the associated beds, in both the Lashio and Namma fields.[203]

[200] V. Ball & R. R. Simpson. Mem. 41. 70 (1913); T. H. D. La Touche & R. R. Simpson Rec. 33, 117-124 (1906).

[201] Rec. 56, 362-383 (1924).

[202] N. Annandale. Rec. 50, 222-223 (1919).

[203] Mem. 57, 30 (1931).

The Man-sang basin, also in South Hsenwi, some 16 miles south of the Namma field, is much smaller than the latter and has thinner coal seams. The silts are undoubtedly the same as those of Lashio and Namma, and the basin exhibits much the same geological features except for the presence of dolerite which not only forms lofty hills to the north but occurs also within the coalfield itself. The beds consist chiefly of yellow white or grey clays with coal seams; the clays are occasionally sandy and there is one thin band of sandstone. The dip averages 15° except along the northern boundary where disturbance has brought about inclinations of 30° and 50°. The basement bed is the Plateau Limestone.

Another basin on the east side of Loi Ling, covering about 36 square miles, contains sediments similar to those of Lashio except that beds of coarse sandstone are more common; there are several seams of coal of doubtful value but these are restricted to a small portion of the basin known as the Man-se-le coalfield. The dip is moderate and the underlying rock is the Plateau Limestone. The only fossils found belong to a species of gastropod identical with one found in the Namma area. Coal is said to exist in several localities north of Bhamo.[204]

To the southwest of Namma, the river, after racing through a three-mile gorge passes through a small oval basin of lake sediments without coal; it is either a disconnected portion of the Namma basin or an independent one.

Similar lake basins are also known in Yawng-hwe, one of the Southern Shan States. Of these the He-ho basin is now a marshy plain, some 7 miles long by 5 miles broad;[205] its altitude is 3,800 feet above sea-level. Towards the margin are large deposits of peat and in this as well as in some of the small ridges of calcareous tufa present are abundant gastropods belonging mostly to species still living in the neighbourhood; in addition there are the following extinct forms, all closely related to species from other lakes or marshes in the neighbourhood: *Taia intermedia, T. lacustris, T. analoga* and *Bithynia* (*Hydrobiodes*) *nassa*, var. *distoma*. Before reaching the gorge which carries the water of the He-ho into the In-le lake, 800 feet below, a small but deep stream has cut down into some older lacustrine deposits of fine grey clay, at least 20 feet thick, and full of shells, most of which are different from those in the superficial deposits; four of these are extinct, *viz.*, *Limnaea* prox. *ovalis, L. shanensis*, var. (species living), *Bithynia* (*Hydrobiodes*) *nassa*, var. *distoma*, and *Taia lacustris*.

The Thamakan basin, a few miles further west, is of much the same size, about 15 miles long and about half that distance in maximum breadth. The deposits lie for the most part upon the Plateau Limestone except where they trespass on to the Jurassic outcrop in the southwest. The beds consist, according to Brown and

[204] Ann. Rep. Rec. 26, 7 (1893).
[205] N. Annandale. Rec. 50, 215 (1919).

Sondhi,[206] of sand, sand-rock, loose pebble-beds and soft conglomerates, silts, clays, loams and lignite, and are for the most part horizontal; the few dips seen, excepting those resulting from collapse due to the solution of the underlying limestone, are no more than gentle warps. The limestone floor is extremely irregular and exhibits a highly serrated profile.

The Inle Lake, southwest of Taung-gyi, has been described by Coggin Brown and Sondhi.[207] It is a very shallow solution lake, lying in a limestone basin and at present about 14 miles in length by 4 miles broad; it is in process of being silted up and is the remnant of a much larger expanse of water which was originally at least 36 and possibly very many more miles in length, with a maximum breadth at its southern end of perhaps 8 miles. At the end of the rains its greatest depth must be at least 20 feet, but in the middle of the dry season it is nowhere more than 12 feet and cannot average more than 7 feet. Its waters contain relatively large amounts of sodium, magnesium and calcium salts. Its highly peculiar fish and molluscan fauna has been described by Annandale, to whose writings the reader is referred.[208] Round the whole of the lake margin but massed especially at the southern end is a rim of floating islands of vegetable matter, both dead and alive; some of the islands have been cultivated. According to Annandale, the matted mass of vegetation, made up of many different kinds of plants but mainly of grasses and sedges entangled with duck-weed, becomes further agglutinated by the luxuriant growth of an alga which belongs to the Rivulariaceae and forms large brownish masses. The decay of this vegetable matter forms a kind of fen peat which is prevented from sinking by floating and growing elements. This formation of peat, which is proceeding in enormous quantities, is of especial interest since, as Brown and Sondhi note, it provides a very probable clue to the mode of production and accumulation of the lignites and coal of the Shan States just described.

The plain of Hopom-Mawkmai in the Southern Shan States has disconnected remnants of sub-Recent terraces at intervals,[209] and old Pleistocene deposits are recorded in the valley of the upper Nam Pawn north of Loilem.[210]

The Kadu Lake, a shallow saline lake in the Sagaing district, covers some 40 square miles but seems at one time to have extended further to the east. It has been the scene of a salt industry, the salt being derived from the local Tertiary rocks.[211] The largest lake in Burma is Indawgyi in the northwest corner of the Myitkyina district, measuring about 16 miles in length and 6 miles across its broadest part; no geological information concerning it appears to be available.

[206] Rec. 67, 192 (1933).

[207] Rec. 67, 179-182 (1933).

[208] Rec. Ind. Mus., 14, (1918); also Rec. 50, 218-220 (1919).

[209] J. Coggin Brown & V. P. Sondhi. Rec. 67, 163 (1933).

[210] J. Coggin Brown & V. P. Sondhi Rec. 67, 148 (1933).

[211] Gen. Rep. Rec. 61, 71 (1928).

Lake deposits of incoherent sand and clays containing beds of peat and lignite are reported by V. P. Sondhi as occurring in the Monghsaw valley near the Sino-Burmese frontier, and may be either of Pliocene or Pleistocene age.[212]

Lakes of this kind and of this approximate age are not confined to Burma but are found in many parts of South-eastern Asia.

Evidence of Upheaval and Submergence along the Coast.— The "raised beaches" seen along the Arakan coast, high above present tidal limits and containing the remains of organisms still living in the Bay of Bengal, bear witness to elevation in Recent times. Ramri Island is evidently a raised archipelago, consisting of an extensive flat of silt through which project the original islands in the form of hill ranges and hill tracts.[213] The ground in and around Kyaukphyu, the chief town of the island, consists mostly of silt. Along the western coast of the island are "raised beaches" of shingle, sand and sea-shells, as well as old sea cliffs; good examples are seen at Minbyin.[214] According to Mallet the east coast is devoid of such features. Three well defined old terraced beaches occur on Cheduba. Foul Island and the Terribles also show evidence of upward movement. Raised beaches and honey-combed cliffs have been noted in both the Andaman and Nicobar Islands.[215] A beach on the Twins, which belong to the Andaman group, is now 6 feet above high tide, while another on the Cinque Islands, made up of fine sand with recent shell fragments, lies about 15 feet above highwater level. On Little Andaman, a platform, evidently the result of coastal erosion was found by Gee to be 10 feet above the present eroded coast level; a small cave well above high tide mark is additional evidence of upheaval. On Tilanchong, one of the Nicobar group, Gee found coral boulders and recent shells inland of Freshwater Bay; along this coast also is a 25 foot cliff of honeycombed limestone. A similar honeycombed cliff occurs at Hut Bay on Little Andaman. On Outram and Lawrence Islands is to be seen a terrace or plateau of marine denudation, 30-40 feet above the sea, and corresponding to that on Car-Nicobar.

On the other hand the archipelagic character of the present Arakan coast suggests subsidence, as also does the presence of a submarine ridge between the Baranga Islands and Cheduba. The Andaman and Nicobar Islands were certainly at one time connected with the Arakan Yoma, and a submarine ridge 700 miles long marks the position of this connection; along this gap lie the islands of Preparis and the Cocos group. The Andamans, Nicobars, Cocos and Preparis are, in fact, nothing more than summits on the submerged continuation of the Arakan Yoma. Thirty miles west, as well as 100 miles east,

[212] Gen. Rep. Rec. 73, 73 (1938).
[213] Mem. 40, 180 (1912).
[214] Mem. 40, Pl. 46, 47.
[215] R. D. Oldham, Rec. 18, 144 (1885); E. R. Gee. Rec. 59, 226, 229-230 (1926).

of the Andamans the depth is 2,000 fathoms. The intricate channels and long ramifying fjords which penetrate the Great Andaman and the adjoining islands bear witness to a considerable depression of the land. In conformity with this deduction, the so-called "Sunda Shelf", which in Pleistocene times was a tract of dry land connecting Java, Sumatra and Borneo with the mainland of Asia, is now a shallow sea; this shelf, the "Sundaland" of Molengraf, is thought to have become submerged after the melting of the Pleistocene ice.[216]

The interpretation of all this evidence seems to be as follows. A general subsidence of some magnitude first lowered the western coast of Burma and was responsible for the formation of Ramri, Cheduba and other islands off the Arakan region, as well as for the isolation of the Andamans and Nicobars which represent the southerly continuation of the Arakan Yoma. The precise date of this movement is not known but it cannot have been younger than the first half of the Tertiary period. The signs of an upheaval belong to a much later epoch and point to a Recent rise of the land. In some places, again there is evidence of a still later depression. The "kitchen middens", on the Andamans, for example, occupy positions where a very slight subsidence would submerge them.[217] On Havelock Island we find more definite signs of this depression as well as evidence of the earlier upheaval. A well developed raised terrace on the west coast witnesses to the latter, while on the north-east coast, which is fringed with alternating low ridge and hollows of forest-covered land; indications of depression are seen in the fact that in the hollows, the forest trees, which are uniform in size with those on the ridges, are all dead, and that the soil is often moist with salt water.[218]

The southern portion of Round Island forms a flat tableland which is evidently an old plain of marine denudation. In the lower northern part of this island is a raised sea beach of pebbles, boulders, lumps of coral, sand and broken shells; at its northern extremity a detached rock on the beach is crowned by an aggregated mass of marine shells, the base of which is about six feet above present high-tide level, the upper surface being covered with grass and shrubs. Similar rocks are found on Flat Island which consists of three terraces corresponding to three successive elevations, the lowest and latest terrace having been formed, according to report, during the great earthquake which partially destroyed Chittagong in 1762.[219] The elevation supposed to have been caused by this earthquake was estimated to be 9 feet in Foul Island, from 12 to 22 feet in various parts of Cheduba, and 13 feet at the Terribles in the northwest of Ramri Islands. While a beach on the west coast of Ramri was raised 20 feet, much of the alluvial area on the east of the island showed no signs of disturbance. At the north end of one of the

[216] See H. A. Brouwer "Geology of the Netherlands East Indies; p. 58 Fig. 1 (1925); G. A. F. Molengraff, Geogr. Journ. 57, pp. 95-121 (1921).

[217] R. D. Oldham. Rec. 18, 145 (1885).

[218] R. D. Oldham. Rec. 18, 143-144 (1885).

[219] F. R. Mallet, Rec. 11, 191 (1878).

Baranga islands oysters were observed sticking to the rock about 2 feet above spring highwater mark. Further north still, the effects of this earthquake were of an opposite character, an area of some 60 square miles in the Chittagong district having been permanently submerged.[220]

There is good reason to believe that the earth movement which produced the Shan Plateau and Arakan Yoma was a part of the movement which raised the Himalaya, and has not yet ceased. The recent changes in level along the Burmese coast and its islands are probably to a large extent the result of continued thrust movements along faults; when such adjustment is sudden and considerable, an earthquake is the accompaniment. As already explained, the Arakan coast and the islands subtending it are subject to earthquakes and disturbances caused by eruptions of petroleum, gas and mud. It would not be easy to distinguish between changes of level due to these causes and those which are the result of tectonic movement whether diastrophic or catastrophic, but the former changes are mostly of ar ephemeral character.

The Burmese Rivers.—Except in the immediate vicinity of the channel itself, there is no important expanse of alluvial deposits in the valleys of the Burmese rivers. Above their deltas their beds are formed largely by Tertiary or older rocks, and there is no continuous alluvial plain such as that found along the course of the Ganges and Indus.[221] Small tracts of alluvium occur here and there, but the wide undulating plains in the neighbourhood of the Irrawaddy or Chindwin in Upper Burma are largely composed of Irrawadian deposits. The lake at Salin and another to the southeast thereof are relics of a former bed of the Irrawaddy. The Irrawaddy at one time continued its southerly course from Mandalay along an old valley now occupied in portions by the lower reaches of the Paung-laung, by its tributary the Samon and by the Sittang river. The change took place within the Recent epoch, since there is a continuous belt of alluvial deposits from Mandalay to the Sittang estuary seldom less than ten miles wide. In Tenasserim drainage is directed for the most part along tectonic depressions.

Compared with the Gangetic and Indus deltas, those of the Irrawaddy and other Burmese rivers are small. The Salwin cannot be said to have any delta at all, and in the Irrawaddy delta, as has already been mentioned, elevated tracts, both of the older alluvial deposits and of earlier rocks, occur not far from the sea. Considering the size of the river, the Sittang delta, if the alluvial plain extending northwards beyond Toungoo be included, is proportionally more extensive than that of the Irrawaddy; nevertheless the broad Gulf of Martaban extends into the very mouth of the Sittang.

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[220] E. P. Halstead, J. A. S. B., 10, 433-434 (1841); F. R. Mallet. Rec. 11, 191 (1878).

[221] The Irrawaddy is the subject of a recent paper by Dr. Dubley Stamp, read before the Royal Geographical Society in February, 1940 and published in May, 1940.

The Irrawaddy delta extends from the Rangoon river on the east to the Bassein river on the west; the head of the delta may be placed 25 or 30 miles northeast of Myanaung. The various rivers and creeks of the Irrawaddy delta are said to be far less liable to change than those of the Ganges and Indus, but it must be remembered that the authentic history of the latter rivers, especially that of the Indus, extends much farther back than does that of the Irrawaddy. The general surface of the Irrawaddy delta near the sea, with the exception of the higher tracts already mentioned, differs but little in elevation from that of the great Indian rivers, and something like 2,000 square miles must be below the level of high spring tides. Large marshes of "*eng*", corresponding to the Indian *jhils,* occupy the depressions between the raised banks of the principal streams, and the whole region, especially in the neighbourhood of the sea, consists of a network of tidal creeks. Owing to the larger proportion of silt transported by its waters, the Irrawaddy has pushed its delta seaward far beyond the Sittang delta. The Salwin traverses for the most part an area of hard metamorphic rocks, and probably brings down very little detritus. The alluvial plain of the lower Irrawaddy and its delta consist mainly of a clay very similar to that found in the Gangetic plain, but containing much less lime and consequently poor in *kankar.* The colour is generally yellowish brown or sometimes reddish, owing to the presence of ferric oxide. The proportion of sand varies, and is greater on the whole than in the Gangetic alluvium. A few thin layers of sand occur interstratified with clay, while a band of dark blue or carbonaceous clay, a few inches in thickness, has been noticed in several localities. This older alluvial clay is believed to be of estuarine or marine origin, gradually elevated to its present position above sea-level, it rests upon the higher portions of the Irrawadian sands, which Leicester believes to pass gradually up into the alluvium.[222]

This delta area and the Gulf of Martaban must originally have formed part of the subsiding geosyclinal tract which received the Pegu and Irrawadian sediments. This subsidence was interrupted by the broad corrugation of the Pegu Yoma and earth movement at the present day in the longitude of Rangoon, appears to have an upward tendency. That this was preceded by subsidence even in Recent times is proved by borings in Rangoon which struck coarse gravel at depths between 200 and 320 feet, some of the pebbles ranging up to one inch in diameter; from one boring, at a depth of 250 feet, were obtained a large number of well preserved marine littoral shells belonging to living species of the genera, *Cardium, Arca, Venus, Solen,* and fragments of Bryozoa.[223] On the other hand recent investigations regarding the water-supply of Rangoon have led to the belief that the peculiar physiographical characters of streams flowing from the termination of the Pegu Yoma are probably due to uplift of the land.[224] P. Leicester has suggested that there are at least two high-

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[222] J. Coggin Brown, Rec. 62, 267 (1929).
[223] R. D. Oldham, Rec. 26, 66-69 (1893).
[224] J. Coggin Brown, Rec. 65, 266 (1931).

level river terraces in the neighbourhood of Rangoon, while minor earthquakes of recent date have been attributed by Coggin Brown to forces of uplift causing movement along lines of weakness below the deltaic alluvium.[225] Supporting the conclusion that the Irrawaddy delta is undergoing uplift are two further facts: first, the comparative narrowness of the river channel between its permanent banks, and secondly, the presence of raised banks of coral near Gwa on the coast, and of shelly sand and shells of living species below the surface of the plains some distance from the coast.[226] On the surface of the clay, in the immediate neighbourhood of the river, deposits of silt and sand are found in some places, and resemble the *khadar* of the Ganges valley. No extensive area, however, is covered by these sandy beds which form but a narrow belt along the river channel above the influence of the tide, and occupy a rather larger area around Pantanau. The so-called sand-banks of the lower Irrawaddy consist mostly of fine silt, characteristically covered by the conspicuous *kaing* grass; the greater bulk of the rice crop of this part of Burma is grown on such extensive tracts of alluvium, a good example being that between Pyinbyu and Minbu. The deposits of the Sittang alluvial plain closely resemble those of the Irrawaddy. Nevertheless, although the Sittang brings down a large amount of silt and sand, the growth outward of its delta is accelerated by the vaster quantities brought down by the Irrawaddy and swept up into the head of the Gulf of Martaban by the flood tides which run up both coasts; these tides concentrate in the Sittang estuary, as is proved by the high tidal bore of this river.[227]

Tenasserim.—In the lowest sections of the valleys of Tavoy, where they join the estuarine flats of the Tavoy river, a fine silt is the only deposit and gives rise to level rice-plains traversed by ramifying tidal creeks. Along the coast sand is almost the only sediment and in both Tavoy and Mergui has yielded natural concentrates of heavy minerals. Of these ilmenite is predominant and monazite is next in importance; there is a little magnetite, an occasional show of gold and a trace of tin.[228] The coast is made up of a series of headlands alternating with bays; each of the latter has a crescentic sand-spit with a lagoon behind largely filled up with accumulations of sand and mud; this lagoon may be open water, mangrove swamp or a salt marsh flooded only at spring tides. The entrance to the lagoon is nearly always at the southern end of the spit.

In Mergui Sethu Rama Rao distinguishes between an older and a newer alluvium, according to their relative position. The older, sometimes gently inclined, is restricted to the larger valleys such as those of the Tenasserim, Lenya and Pakchan rivers, where it attains a thickness ranging up to 60 feet. It consists of beds of ferruginous sandstone and conglomerate, gravel and white clays; some of the beds bordering the Tenasserim are composed of impure kaolin derived

[225] Rec. 62, 278 (1929).
[226] E. H. Pascoe. Mem. 40, 210 (1912).
[227] J. Coggin Brown. Rec. 65, 264 (1931).
[228] A. M. Heron, Rec. 48, 179 (1917).

from the neighbouring granite slopes. The newer alluvium, which is always horizontal, is seen in all river valleys and deltas and along the sea-coast. It consists of alternations of sand and fine silt except in the upper portions of the river valleys, where it includes gravel and sand. The more extensive river flats are usually cultivated with paddy.

In the rain-drenched region of Tenasserim the decomposition of the Mergui rocks is described by Brown & Heron as having penetrated to a remarkable depth. The first stage is the oxidation of the ferrous constituent to ferric oxides and hydrates, and the opening of the close and irregular joint planes, the result being a red-brown rock still hard but breaking into splinters.[229] Passing upwards, this is seen to soften and lose coherence till it becomes a compact lithomarge mottled in shades of brown, red and purple. This stage, which varies considerably in thickness according to the slope, is in turn broken up by surface creep and the disintegrating action of tree roots, graduating with the addition of vegetable matter into the ultimate stage of weathering, which is a brownish red clayey soil covering all the hillsides except where granite is the underlying rock.

Laterite is found only on low-lying flat land, where the sub-soil is water-logged for the greater part of the year; it is for instance common, though seldom more than 3 feet in thickness, in the bottoms of the broader valleys where the streams have little erosive power but are not slow enough to deposit silt.

Cassiterite and wolfram are obtained from detrital or eluvial deposits in the neighbourhood of the Tavoy Granite in the districts of Tavoy and Mergui; they may occur on any hill slope in or above which parent mineral lodes are undergoing degradation, a comparatively rapid process in such a rainy climate.[230] Cassiterite also occurs in the true alluvial or placer deposits of streams draining these granite intrusions or crossing their contacts with the overlying sedimentaries. Wolfram is not found, except in the merest traces, in true alluvial deposits; this is due to its rapid disintegration and easy communication resulting from its perfect cleavage, and to its ready yielding to both acid and alkaline solutions, which produce the friable yellow tungstite or soluble alkaline tungstates, as the case may be. These Pleistocene or late Tertiary deposits are of considerable extent and importance, for it is in them that the richer cassiterite placers are likely to occur.[231] They are found as river terraces of gravel and sand, raised above the present level of the inland streams; as lacustrine and fluvio-lacustrine sediments laid down in the still waters of the Myitta and other lakes; as deep eluvio-alluvial beds in the submerged basin of Kanbauk and other places; and as clay banks containing marine fossils and now raised above the level of the sea, as in the vicinity of the Tavoy estuary. The mineral is obtained by ground sluicing; the upper parts of the valleys have been much

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229 Mem. 44, 180 (1923).

230 J. Coggin Brown & A. M. Heron, Rec. 50, 117, 120 (1919).

231 J. Coggin Brown, Rec. 49, 29 (1918).

worked in the past. Besides cassiterite the concentrates contain topaz, magnetite, ilmenite, garnet, zircon, monazite and small amounts of gold. The beds of the Myitta valley are composed of pebble banks and gravels loosely cemented together, soft shales and sand-rock, with interbedded thin seams of lignite and rare pieces of silicified wood. Attaining a maximum depth of at least 50 feet and covering scores of square miles, they correspond probably to the coal-bearing beds of the Great Tenasserim valley. The clay bands show a slight dip in varying directions. The lignite is of no commercial importance. The Myitta is typical of other lakes, but is the largest. The deposits of Kanbauk are described by Coggin Brown as having accumulated in a rapidly sinking valley which must have stood at a higher level at one time than it does today.[232] According to this observer, there is evidence of a general depression of the coast-line and interior of Tavoy, but the interior regions appear to have been affected by a more recent uplift. Most of the larger streams of this district are characterised by raised river terraces. In the open upper valley of the Tavoy river, above Kaleinaung, the river is now cutting down through slightly consolidated horizontal sands overlying coarse conglomerates ; and forming cliffs about 20 feet in height.[233] At the head of the lower portion of the valley similar conglomerates crop out as bars across the stream and are probably widespread elsewhere but concealed beneath later accumulations. The cassiterite-bearing and auriferous coarse boulder conglomerates, on which the civil station of Tavoy is built, may belong to the same period but may equally well be of late Tertiary age. The cassiterite and topaz bearing gravels with a white clay matrix which are dredged for tin on the Hindu Chaung, a tributary of the Tenasserim, are in all probability of the same age ; an elephant tooth from the gravels belongs to a form closely allied to the modern Siamese elephant.

Of the few old river terraces found in the Northern Shan States, the most important are the ruby gravels of the Mogok valley and the surrounding district, the tourmaline gravels of Mong Long in the valley of the Nam Pai, and some terraces in the valley of the Nam Tu.[234] Deposits of calcareous tufa or travertine, derived from the Plateau Limestone and of huge dimensions, have been noted by La Touche, and in the smaller streams from dams or natural weirs. This material has been deposited on the precipitous sides of gorges and in some cases extends completely across the stream to form a natural bridge. Of such a nature is the famous natural bridge over the Gokteik gorge, midway between Maymyo and Lashio, formed mainly from springs on the southern side ; used for ages by Chinese and Shans for crossing this deep canyon, it now carries the supports of the railway viaduct. The building up of this bridge has been assisted by talus from the cliffs above its upper surface being now 550 feet above river level.[235] Further east the railway passes through a

[232] J. Coggin Brown, Rec. 49, 29 (1918).

[233] J. Coggin Brown & A. M. Heron, Mem. 44, 196 (1923).

[234] T. H. D. La Touche, Mem. 39, Art. 2, 319-321 (1913).

[235] T. H. D. La Touche, Rec. 33, 49 (1906).

cutting several hundred yards long and a hundred feet or more in depth, entirely excavated in travertine derived from springs on the hillside.[236]

Soils.—The universal mantle of somewhat sterile red clay, spread over the limestone of the Northern Shan States, is described by La Touche as one of the most striking features of the plateau country. The prevailing colour is a bright Indian red, sometimes with a slight orange tint when dry, and becoming much darker when wet.[237] It has already been described (p. 1943). Since the amount of insoluble matter in those dolomites and limestones averages probably less than 0.5 per cent. and scarcely ever more than 1 per cent., enormous quantities of the parent rock must have gone to the formation of this residuary clay which in places attains a depth of 40 or 50 feet.[238] Since the removal of soluble material from the superficial layers of the Plateau Limestone and the concentration of iron have been proceeding since the Shan plateau emerged from the sea in late Mesozoic times, the formation of this soil cap probably dates from the Cretaceous.

Where the Shan plateau is gently undulating and there is no very high ground in the neighbourhood, water issuing from springs either sweeps away the covering of red clay or prevents its formation; the result is a rank growth of aquatic plants and grasses which accumulate and form a black soil resembling peat.[239] Saltpetre is reported to occur in Lawksawk, one of the Southern Shan States, and used to be extracted in the time of the Burmese kings.[240] A variety of *regur*, known as *pu-tchi*, is found in Kyaukse, and much of the rest of the district is covered with a dark coloured clay soil known as *sa-ne*; the distribution of these soils appears to be related more to the original distribution of forest and open country than to the nature of the underlying rocks.[241] Nevertheless the underlying country rock does in some cases play a critical part in soil formation; sugarcane, for instance, while thriving on a soil supported by the schistose crystalline rocks, fails entirely on a serpentine soil.

IV. ALLUVIAL GOLD

The gravels and sands of most Indian and Burmese rivers, whether in the Peninsular or Extra-peninsular regions, yield small quantities of gold when panned, and a precarious livelihood is usually made thereby by a few local inhabitants, such as the *Sonwals* of Assam or the *Jhoras* of Chota Nagpur. Some river gravels produce more than others and attempts have been made to exploit them on a commercial scale, but the capriciousness of the occurrences of the metal, due especially to the complete disturbance suffered by the gravels every year by the monsoon floods, has always proved a

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[236] T. H. D. La Touche, Rec. 33, 52 (1906).
[237] T. H. D. La Touche, Mem. 39, Art. 2, 322 (1913).
[238] J. Coggin Brown, Rec. 61, 191 (1928).
[239] T. H. D. La Touche, Mem. 39, pt. 2, 330 (1913).
[240] Gen. Rep. Rec. 69, 44 (1935).
[241] Gen. Rep. Rec. 55, (1923).

formidable obstacle.[242] In most cases the lack of concentration and the universal and widespread distribution of the metal in small quantities in the deposits offer no incentive to development on a large scale. As a rule the gold is most abundant in the beaches at the ends of long pools in the river valleys, especially when high banks are being eroded, and in the longitudinal boulder beaches to which the metal is carried by back eddies. In Chota Nagpur and Assam the alluvial gold appears to have been derived from quartz veins in the ancient crystalline schists. The gold of Assam is mentioned in the second book of the Mahabharata and in later histories,[243] and is not derived from Tibet as was at one time supposed since, in the first place, it is found above the mouth of the Dibong and, secondly, the gravels of the Tsangpo are known to be extremely poor in gold. It occurs in the Tipam sandstone as well as in the river alluvial deposits and is thought to have come from quartz veins in the crystalline schists of the Miju ranges beyond the Brahmakhund. The best yielding locality appears to be the Subansiri gorge. The native methods of washing for the metal are described by Maclaren.[244]

The sands of the Chitral river have yielded in addition to gold some cinnabar, the only occurrence of any ore of mercury so far reported in India.[245]

In Burma the upper reaches of the Irrawaddy, between Bhamo and Myitkyina were for several years extensively dredged for gold, the average annual output from 1914 to 1918 inclusive being 1,951 ozs.[246] The Chindwin gravels have also attracted attention, both those of Recent and Pleistocene age ; these and the Irrawaddy gravels yield in addition to the gold small quantities of platinum and platinoid metals derived perhaps from serpentine. The local industry on the Chindwin dates back to before the time of King Mindon.[247] Platinum as well as gold is found along the Uyu river. The alluvium and Upper Tertiary conglomerates of the Hukawng valley were formerly worked for gold by the Kachins with the aid of slave labour ;[248] some of the river sands in Kachin have yielded 30 grains of gold to the ton.[249] Gold is found in the detritus of most of the streams which drain Chaung Magyi rocks in the Northern Shan States and is thought to have come from those rocks as well as from the veins of quartz therein.[250] The Nam-ma and other rivers have yielded small quantities of the precious metal. Nuggets of gold are reported to have been found in the Akyaung valley between the Nmai Kha and the Chinese border. A gravel in the Paunglaung valley of the Southern Shan States has been worked extensively for gold by the Chinese.[251]

[242] Gen. Rep. Rec. 32, 141 (1905).
[243] J. M. Maclaren, Rec. 31, 205-206 (1904).
[244] J. M. Maclaren, Rec. 31, 212-217 (1904).
[245] Gen. Rep. Rec. 54, 26 (1922).
[246] L. L. Fermor, Rec. 70, 113 (1935).
[247] Gen. Rep. Rec. 61, 56 (1928).
[248] H. S. Bion, Rec. 43, 241 (1913).
[249] Ann. Rep. Rec. 26, 7 (1893).
[250] J. Coggin Brown, Rec. 42, 40-41 (1912).
[251] Gen. Rep. Rec. 71, 40-41 (1936).

CHAPTER XXXVI.

LATERITE.

Tertiary and earlier laterites. Mode of occurrence and general characters. Origin. Age.

Tertiary and earlier laterites.—It is impossible to travel far in India without meeting with the remarkable, residual, ferruginous rock to which F. Buchanan in 1807 gave the name of laterite.[1] Whatever its precise mode of formation may have been, the presenec of this rock or of any rock of a similar nature in a stratigraphical succession marks the position or immediate proximity of a land surface and soil. Deposits equivalent in all respects to true laterite and others similar in some features but differing in others, have been observed at several levels between members of the Tertiary system ; allusion to such has already been made, and to the stratigraphical break which they invariably indicate. As an example of such, and one which has not been previously referred to in this work, may be cited the laterite and kaolinised rock found by Fox in the Garo Hills of Assam ; this laterite, which covers kaolinised gneisses and sometimes basalt and dolerite dykes, is clearly overlain by early Tertiary sandstones (the Tura sandstones) believed to be of Eocene (? Palaeocene) age.[2]

Soil caps of the nature of laterite are not limited to Tertiary and post-Tertiary horizons but may occur presumably at any level throughout the geological scale. Even among Archaean rocks such layers appear to be recognisable. As an example Dunn found in the Dharwars of north Singhbhum a band of laterite or lateritic clay along the boundary of the main flows of the basic igneous rock now represented by epidiorite, and suggests that the lateritic alteration may not be entirely recent—*i.e.*, not a selective superficial process affecting only exposed outcrops—but may be in part contemporaneous with the early flows as a result of prolonged weathering between successive outpourings. Thin bands of laterite, found occasionally in the mica-schist country of this district, may represent altered epidiorite dykes or sills among the schists, occurring, as they frequently do, along the same line of strike as unlateritised intrusions of epidiorite.[3] The eroded edges of the upturned rocks of this area are at the same time covered with patches of laterite which is of more or less recent formation.

Mode of occurrence and general characters.—The occurrences now to be considered are superficial ; they cover a very large area in the Indian peninsula and are found also along the sub-Himalaya and in

[1] "Journey from Madras through Mysore, Canara and Malabar": London, 1807, II, p. 440.
[2] Rec. 68. 76 (1934).
[3] Mem. 54, 143-144 (1929).

Burma. To call laterite a formation would be to strain the use of the term, for there are two chief types, both of them in process of being formed at the present day. Nevertheless, although the term belongs essentially to a form of rock, it is not without stratigraphical significance. The two types are known as Primary and Secondary, the latter being a detrital deposit derived from the erosion of the former. The terms High-level Laterite and Low-level Laterite have been widely applied to the Primary and Secondary types respectively, and emphasise the important distinction that the older occurrences are in the great majority of cases found at a higher level than the younger; the former in fact are seldom seen below the 2,000-foot contour, while the latter are not often seen above it. There are, however, exceptions and laterite known or believed to be of secondary origin is sometimes seen at comparatively high levels, as for instance in Seoni, Vizagapatam and parts of Satara; on the other hand, in some places of which South Malabar is an example, a considerable amount of low-lying laterite appears to be non-detrital in derivation and formed by the decomposition *in situ* of the underlying gneiss accompanied by a certain amount of rearrangement by rain. According to C. S. Fox, who is responsible for one of the latest contributions to the vast literature upon this interesting form of rock,[4] the two types are in most cases readily distinguishable in the field; in hand specimens, on the other hand, they are often indistinguishable. Some occurrences are obviously mixtures of the two kinds. In any case the great similarity in general appearance and the possession of numerous common properties make it convenient to describe both Primary and Secondary Laterite under one heading.

Laterite is by no means confined to India, but is a widespread, usually unfossiliferous product of tropical or sub-tropical regions. It has been recorded not only from Ceylon, Burma, the Malay peninsula and the East Indies, but also from parts of Europe, many of the United States of N. America, British, Dutch and French Guiana, Brazil, central, west and east Africa, the Seychelles Islands and Western Australia. The term, laterite, has been loosely applied in the past. To Lewis Fermor we owe the suggestion of the name, "Lateritoid", for rocks which, although resembling true laterite in some respects, differ in failing to possess an excess of aluminium hydroxide, quite subordinate silica and varying but often considerable quantities of iron hydroxide and titania. To this category of "Lateritoid" are to be referred the ferruginous clays on the Nilgiri hills, at one time reported as laterite. True laterite is a complex product of weathering in a hot moist climate, and may be defined as characterised essentially by the presence of free hydrated alumina, but usually containing at the same time notable amounts of titanium and iron oxides, whilst free silica is generally present though in most cases in very subordinate quantity, and silicate of aluminium is not necessarily absent; the amount of iron is very variable but when excessive it usually separates out as concretionary iron ore.[5] The lateritisation of a rock.

[4] Mem. 49 pt. 1 (1928).

[5] See T. Crook, Bull. Imp. Inst., p. 524 (1909).

in the opinion of Fermor, involves the disappearance, probably in solution, of the silica, lime, magnesia and alkalies of the parent rock, with the concentration of the hydrated oxides of aluminium, iron, titanium and sometimes manganese. The essential feature of laterite, as noticed by J. W. Evans, and one which distinguishes it from the clays which also occur as tropical decomposition products, is the small amount of combined silica in proportion to the alumina present. Laterite and clay are, in fact, the end products of two quite distinct modes of decomposition. The presence of free silica, especially in the form of quartz, is usually an indication that the laterite is of detrital origin, unless the silica fragments are the relics of geodes.

On exposure the surface of laterite usually becomes coated with a brown or blackish brown crust of limonite, but, when freshly fractured, the rock is mottled with various tints of brown, red and yellow, while a considerable proportion sometimes consists of white clay. The iron, present as peroxide either entirely or partially hydrated to limonite, occurs not infrequently in the form of small pisolitic nodules which are sometimes used as iron ore. Veins and nests of black oxide of manganese are observable in some of the laterites of the Deccan. The difference in tint is due to the segregation of the iron in the harder portions of the rock, the pale yellow and white non-ferruginous parts being very much softer and liable to be washed away on exposure. Occasionally the white portions have a brecciated appearance, consisting of angular fragments in a ferruginous matrix; in such cases the rock may have a compact texture like that of jasper though never so hard.

Laterite is a highly porous rock. When first quarried it is sometimes so soft that it can be easily cut out with a pick or even a spade, but hardens very much on exposure. It is this facility with which it can be dressed into brick like blocks which has given it the name of laterite (Latin, *later,* a brick) and which makes it so useful for building purposes. The hardening is due not merely to the desiccation of the argillaceous constituents but to a change in the distribution of the ferric oxide, the rock becoming darker while its outer surfaces as well as the surface of the peculiar tubular structure it often possesses within, develops a glaze of limonite. This segregation of the iron has evidently tended to obscure any structure which may have existed originally in the rock; in some forms of the rock this segregation has resulted in the formation of pisolitic nodules of hydrated ferric oxide.

Laterite shows every gradation from a ferruginous type almost free from alumina to aluminous laterite almost free from iron; when pure enough to be used as an ore of aluminium, the laterite is known as bauxite. Bauxite is probably a mixture of two hydroxides corresponding to gibbsite ($Al_2O_3.3H_2O$) and diaspore ($Al_2O_3.H_2O$), the latter and most of the former being in an amorphous condition.[6] Fox suggests that the constituents of laterite—at any rate the hydroxides

[6] C. S. Fox, Mem. 49, pt. 1, 19 (1923).

of aluminium, iron and possibly titanium—may be present in the form of colloidal *gels* with very variable H_2O contents; the only mineral sometimes showing a crystalline structure and recognisable under the microscope is gibbsite. The basalts of the Deccan Trap are pre-eminently the rocks from which the laterite of the Indian peninsula has been derived; the presence of titanium oxide (TiO_2) in the laterite is a safe indication that the latter has originated from the Trap, which contains an appreciable percentage of titanium.

Chemical analyses of such a variable rock as laterite are of limited value. The following by W. R. Dunstan are of samples of the Primary variety from the Balaghat district of the Central Provinces, sufficiently rich in alumina to be termed bauxite, and will serve to exhibit the very low proportion of silica and the unusually high percentage of titanium;[7] approximately one quarter of the rock consists of combined water:—

	Near Rupjhar				N. of Samnapur	
	No. 1	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*
Al_2O_3	53·52	56·63	58·83	54·95	54·12	52·14
Fe_2O_3	10·58	5·34	2·70	7·00	4·06	7·55
MnO	..	trace	..	trace	trace	trace
MgO	0·61	..	..	..	0·33	..
TiO_2	6·22	7·02	10·24	13·76	11·82	11·66
SiO_2	1·83	2·65	0·58	0·37	1·54	0·60
K_2O	0·30	0·12	0·12	0·06	0·07	0·13
Na_2O	0·89	0·39	0·13	0·36	0·14	0·21
Combined water	24·04	27·14	26·80	22·76	26·87	27·09
Moisture	0·91	0·86	0·40	1·14	0·65	0·71

The specific gravity increases after soaking the rock in water. In the more ferruginous varieties of the rock a percentage from 21 to 28 of ferric oxide (Fe_2O_3) is not above the average in a Deccan laterite.

More ferruginous varieties of the rock have the well known vermicular structure, characterised by tortuous tubes from ¼ to 1 inch in diameter, sometimes vertical or nearly so, sometimes horizontal, but generally quite irregular and with no predominant direction. The tubes are lined with a limonitic glaze and, except near the surface, filled with cream-coloured powdery lithomarge. From analyses Fox finds that the fillings are much more highly aluminous than the red matrix. In the detrital varieties it is often possible to discern grains of quartz embedded in the rock. Horizontal cracks, occasionally expanding into small cavities, are sometimes seen, producing an appearance of irregular stratification. The exposed surface, whether vertical or horizontal, is peculiar and characteristic. It is extremely irregular, being pitted over with small hollows caused by the washing

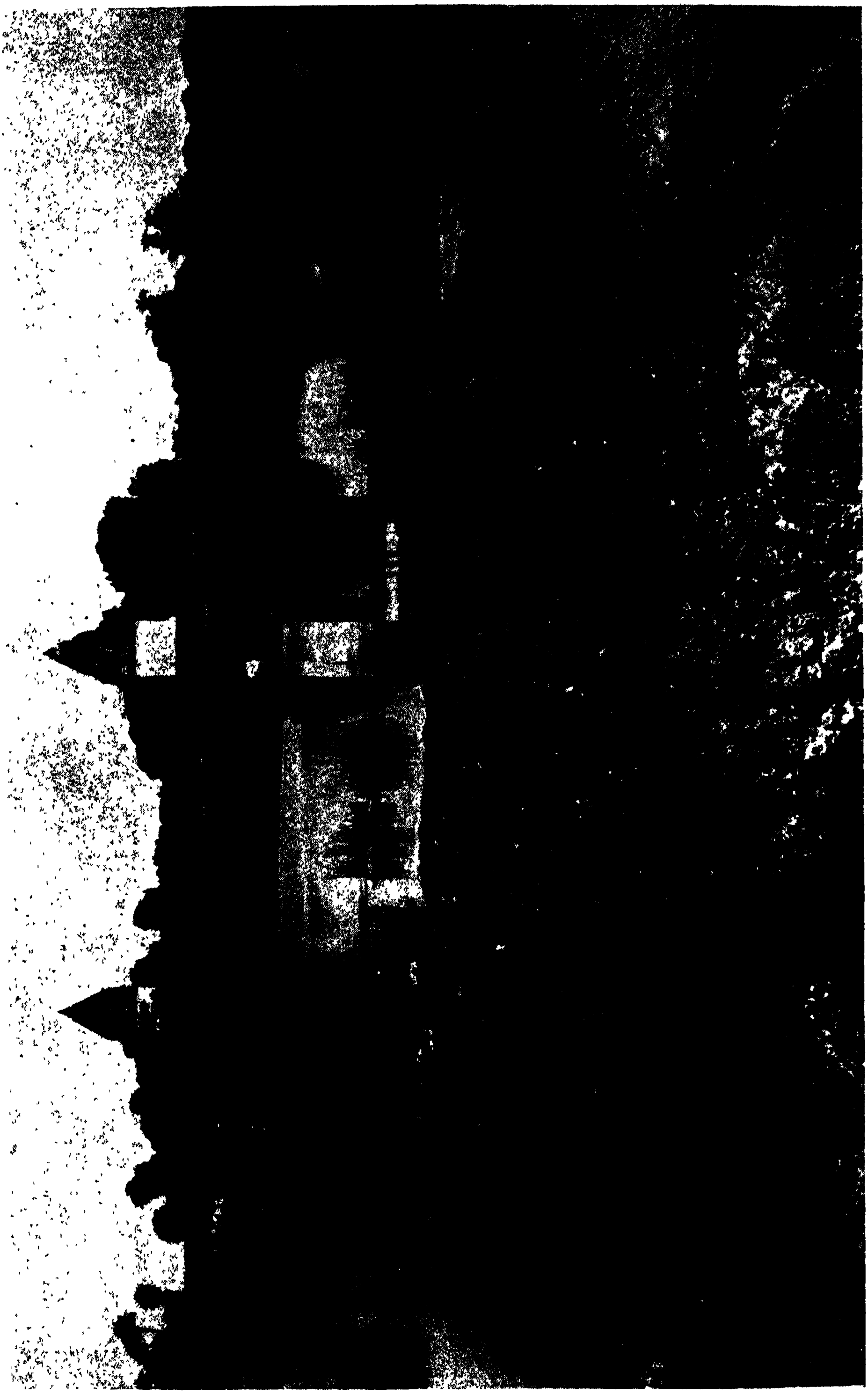
[7] Rec. 37, 215 (1908).

away of the softer fillings, and frequently, though not always, traversed by the tubes and cavities just described. At times it is so broken up by small holes as to appear vesicular, whilst the crust of limonite forms a brown glaze, often mammillated or botryoidal. Affected in this way the rock has a remarkably scoriaceous appearance and bears a very curious resemblance to an igneous product; this deceptive similarity is enhanced by the widespread and close association of the rock with basalt and other igneous types. Pisolitic structure is developed only near the surface or in zones of infiltrating water. The exposed surface, both in the Primary and Secondary varieties, is very frequently pisolitic or oolitic. It is mainly this superficial layer which yields iron ore and, in one or two places, manganese ore of commercial importance, such ore occurring as pisolitic or botryoidal nodules, or in streaks and veins. In the more massive bauxitic forms some horizontal banding is usually present. Fox notes that the change from the pisolitic ferruginous mantle to the grey bauxite, often seen a little below the top of a section of Primary Laterite, is remarkably sharp; further downwards there is in typical cases a gradual change from the aluminous to the ferruginous variety of the rock, and the basal part of a laterite section is in fact not uncommonly of a highly ferruginous character.[8] In some cases, as for example in Seoni, the bauxite is interbedded between two layers of ferruginous laterite.[9] Primary bauxite, massive though it is, has a somewhat brecciated appearance.

In India the country rock supporting any cap of high-level laterite is in the majority of cases, though not always, the parent of the latter. and may consist of basalt, epidiorite, schist, gneiss, granite and other types common in the Peninsular region. Most frequently laterite forms flat or slightly undulating plateaux on the Deccan Trap. It is found on the mica-schists of north Singhbhum, which are clearly seen altering to laterite, and still more conspicuously upon the epidiorites of that area, often capping the highest hills. Round the margins of the Deccan Trap laterite is often found lying upon the Lameta beds. In Rajpipla it is said to have originated from Tertiary clays.[10] The laterite which is seen in Panna resting on Vindhyan sandstone probably belongs to the detrital variety.

In Vizagapatam and Ganjam its occurrences are mostly confined to the Archaean schists, from which they appear to have been directly derived;[11] in the latter district the coarse granitic rocks, on the other hand, are said to be free from patches of laterite. In Sambalpur it is described as passing down by insensible gradations into the underlying gneiss.[12] In Kalahandi the flat-topped Korlapat hill of khondalite, 3,800 feet high is capped by laterite which in places is bauxitic.[13] In Malabar, Kanara and Shimoga laterite has been formed from the underlying granitic rocks, down into which it passes through a kaoli-

[8] Mem. 49, 15 (1923).
[9] Rec. 48, 205 (1917).
[10] Rec. 37, 175 (1908).
[11] Gen. Rep. 1901-1902, p. 23.
[12] Gen. Rep. 1897-1898, p. 46.
[13] M. S. Krishnan, Rec. 59, 420 (1926).



nised zone.[14] In the plain of South Kanara Sampat Iyengar refers to the horizontal table-like capping of laterite on Peninsular Gneisses, large boulders of which can be seen altering into massive laterite.[15] In the Raniganj coalfield laterite, including the Primary type, lies upon Gondwana rocks.[16]

Primary laterite frequently appears to pass down into the underlying parent rock, whether this be igneous, metamorphic or sedimentary. If this subjacent rock be basalt or gneiss, its upper part is decomposed or kaolinised to form a clay or lithomarge passing upwards into the laterite. This intermediate material is exceedingly variable in character but always more ferruginous above than below; sometimes it contains a few pipes, apparently produced by the percolation of water. It may occur in thick beds of almost white to pink, finely laminated clayey matter, it may be thin and interbanded richly with limonite, or it may consist of alternations of clay, grit and ferruginous bands. It has the general appearance of a sediment but, according to Fox, it has a complicated internal structure and appears to thin out when traced inwards under the laterite mantle. In many other places this lithomargic zone, consisting of bands of ferruginous grit and stiff laminated clay, sometimes sandy and generally ferruginous, shows no tendency to pass into the underlying rock, though usually exhibiting an unmistakable transition into the laterite above. In such cases the laterite and lithomarge together constitute a group of beds superposed, as a rule unconformably, upon older rocks of various kinds. Such conditions have been noted in parts of the Central Provinces and Central India, the laterite and its accompaniments resting with a clean junction upon the Trap like a distinct formation. In some instances, as in Bundelkhand, this infra-lateritic layer contains pebbles and there is every reason in that case for believing that it is a rock of sedimentary origin. Occasionally the lithomargic layer contains hematite or limonite in quantities sufficient for commercial exploitation, as in Bundelkhand, in the neighbourhood of Jubbulpore and on the eastern flanks of the Rajmahal Hills.

One peculiarity possessed to an eminent degree by all forms of laterite is its capacity for reconsolidation, broken fragments being recemented with great ease into a mass closely resembling the original rock. Laterite itself has great powers of resisting atmospheric disintegration, being a product of the prolonged action of the atmosphere, and the only change noticeably suffered by its persistent and relatively indestructible constituents is a certain amount of dehydration. The underlying formation, however, as a result of decomposition, is slowly washed away, and the originally horizontal cap of laterite, after falling down, becomes reconsolidated on the irregular floor which it still covers.

The surface of the country covered by the more solid forms of laterite is usually very barren, the trees and shrubs growing thereon being sparsely scattered and of small size. This infertility is due in

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[14] C. S. Fox, Rec. 69, 396 (1935).

[15] Rec. Mys. Geol. Deptt. 17, 102 (1919).

[16] Gee, Mem. 61, 71 (1932).

great part to the high porosity of the rock, all water sinking into it to such an extent that sufficient moisture is not retained in its topmost layers to support vegetation. Some of the more gravelly or more argillaceous varieties of the rock are exceptional in this respect, but most of the laterite plateaux are bare of soil, and frequently almost devoid of vegetation.

Primary laterite is a rock of sub-aerial formation, fine-grained and, apart from the irregular distribution of the iron contents, comparatively homogeneous in texture. It forms a cap or mantle to the rocks of many plateaux, occurring especially on watersheds which have not been subjected to extensive denudation. It is chiefly developed on parts of the Deccan plateau, especially on the highest portions of the Western Ghats and of the spurs projecting therefrom. It forms a cap on the uppermost Traps exposed on the plateau, but is found also at lower elevations where, however, it is usually of small extent and thickness. The summit bed, as it has been called, is not more than 50 or 90 feet in thickness in the southern Maratha country; at Mahabaleshwar it is about the same, but at Bidar to the northwest of Hyderabad it has swollen to 100 or 200 feet. At Ganjam it reaches a thickness of 200 feet in places; along the northern and western margins of Bhopal State in Central India it is from 50 to 80 feet thick.[17] In Balaghat it is over 100 feet thick and is underlain by another 100 feet of lithomargic clays passing down into the Deccan Trap.[18] In Seoni it is sometimes as thick as 110 feet.[19]

Primary laterite occurs at varying heights above the sea, but not above an elevation of 5,000 feet in western India and somewhat less on the Eastern Ghats. Always overlying the highest lava flow, it is found in the Bombay Presidency at 4,710 feet near Mahabaleshwar—a maximum elevation—3,177 feet at Panhala Fort, 3,333 feet at Kalanandigar, 2,700 feet on Matheran hill, 700 feet at Harnai, and 60 feet at Vijaidurg. Similar ranges of heights are found in Central India, in the Central Provinces and in Bihar and Orissa. Some of the caps are extensive, that at Bidar being 28 miles long by 22 miles broad; forty miles further west is an even larger tract.

The bulk of the laterite of India is found near the Western Ghats and in the southern Maratha country, lying with its lithomargic accompaniment upon a floor of Trap. A few very small caps are found in southeastern Berar and similar small outliers occur here and there along the southeastern margin of the main Trap area. Further northeast laterite occurs at Amarkantak and on the eastern outliers of the Deccan Trap at Main Pat and Jamira Pat in Sarguja, being from 100 to 200 feet thick on the former. In several parts of Seoni, Balaghat, Mandla, Udaipur and the *pats* of Sarguja roughly horizontal sheets of laterite cap on the Trap at altitudes of 2,000-3,500 feet occur.[20] In Balaghat and Jubbulpore the laterite is said to have

[17] Rec. 33, 108 (1906).
[18] Rec. 47, 38 (1916).
[19] Rec. 48, 204 (1917).
[20] Rec. 50, 269 (1919).

PENCHGANI LATERITE TABLELAND
CLOSE VIEW OF TOP.

G. S. I., Calcutta.

suffered disturbance.[21] North of the Narbada also, in Rewa, Bundelkhand and other States, as far west as Gujarat, laterite sometimes as much as 200 feet thick is seen capping outliers of the Trap. In such isolated occurrences it evidently at one time formed a continuous horizontal sheet, as did the Trap on which it lies, the dissected outliers being the result of denudation.

Outside the Trap area, caps occur at high elevations on the Dambal or Kappatgod hills, east of Dharwar, and on hills in the neighbourhood of Bellary and Cuddapah. More to the northeast, in the high ground of Patna, Kalahandi, Bastar, Jaipur, etc., between the Mahanadi and Godavary, caps of laterite, 50 to 100 feet or more in thickness, occur on many of the higher hills at elevations of between 2,000 and 4,000 feet above the sea. In Vizagapatam laterite from 80 to 100 feet thick is limited to a well marked horizon which lies some 3,500-4,000 feet above sea-level and, in its uniformity and extent, has the appearance of being a plain of marine denudation. Hills above 4,000 feet in this area are never capped by laterite and project through the latter like islands ; on the inward side of these terraces is a shingle deposit of rolled and partly rounded pebbles of the underlying Khondalite rock, set in a pisolitic laterite matrix, but with no fossils.[22] A similar projection of gneissic islands through laterite is recorded in south Malabar. In Kolhapur high-level laterite is seen lying on flat or undulating plateaux usually above 2,900 feet in height ; small vertical cliffs of 20-100 feet are here often produced by the falling away of blocks of laterite, disclosing the basal band of kaolin or lithomarge and decomposed trap.[23] The most eastern exposure known to occur in this neighbourhood is on Kopilas hill, about 2,050 feet above sea-level and twelve miles north of Cuttack. To the northward a great expanse of laterite is spread over the Chota Nagpore plateau at elevations varying from 2,000 to 3,000 feet above the sea, and is especially well developed to the northwest of Jashpur ;[24] here it caps ridges and peaks in the usual manner but differs from normal high-level laterite in covering hills and valleys alike, and is most probably in part a reconsolidated product. Leaving for a moment the Rajmahal Hills, which deserve separate notice, a thick mass of laterite occurs at an elevation of 1,500 feet on Moira hill, the highest peak of the Kharakpur range. Turning thence westwards, caps of the same rock are found, outside the Trap area, in the Raniganj coalfield, at several places in Bundelkhand[25] and at two places near Gwalior,[26] all on the highest ground of the country.

In the immediate neighbourhood of the Trap margin, where the Trap is apt to become very thin, there are several instances in which none of it has survived the disintegrating forces ; in such cases the whole layer of the trap has been converted into laterite now lying

[21] Rec. 32, 144 (1905).
[22] Gen. Rep. 1902-1903, 25.
[23] Rec. 54, 418 (1922).
[24] Rec. 10, 170 footnote (1877).
[25] Mem. 2, 82 (1860).
[26] Rec. 3, 41, (1870).

directly upon the ancient rocks which were previously the local floor of the Trap. Fox has traced examples of this apparent "overlap" beyond the edge of the Trap and has found isolated cappings of laterite with no visible trap beneath them ten or twenty miles away from the nearest Trap exposure. That these caps once covered the thin edge of the Trap is proved by relics they contain of the volcanic suite; these relics take the form of nodules of basalt or fragments of the geodic material which is so characteristic of the Deccan Trap flows. By making further use of this interesting discovery, it might have been possible to form a more accurate estimate than has been hitherto possible of the original extent of the Deccan Trap, were it not for the known scarcity of geodic relics in the laterite. The deduction that a thin layer of trap originally underlay the soil-cap in process of lateritisation and separated it from the rock on which the laterite now lies, explains the anomalous occurrences of laterite upon quartzite, limestone and other rocks which, from their composition, are incapable of giving rise to such a highly aluminous and ferruginous product. Fox instances Katni and Gosalpur as two localities at which fragments of the typical agate geodes, so common in the Deccan Trap, have been found in the laterite; at Katni the laterite or bauxite, with its underlying lithomargic layer of kaolin and silica now rests upon Vindhyan limestone, while at Gosalpur its present floor is composed of phyllites and quartzites of Dharwar type. This lateral disappearance of the Trap is also well seen in the Ranchi district, where, lying below the laterite, it thins out eastwards from the Sarguja and Palamau border and disappears almost entirely in the tangle of hills west of Lohardaga; here all that remains consists of fragments of basalt, geodes, and a bed of lithomarge at the base of the laterite, the whole resting on a granitic gneiss. This quasi "overlap" of the Trap by the laterite on to older rocks had not escaped the observation of investigators in the past.[27] In the southern Maratha country it had been noticed that the same laterite bed was sometimes continous from the Trap surface on to the metamorphic schists, and numerous outliers on the latter were recorded. It is, however, not claimed that all Primary laterite in India has been derived from the Trap and, although we may conclude with Fox that "Lateritisation of these basaltic lavas accounts either directly or indirectly for nearly all the laterite in India", we may agree with the same authority that there is evidence to show that Primary laterite "is a residual weathering product of various types of igneous, sedimentary and metamorphic rocks"; it appears to be genetically related to the gneissose granite of Vengurla, the khondalites of Kalahandi, or the Talchir clays of Chhattisgarh, as well as to the Deccan basalts. Sometimes it is an exposed Inter-Trappean sedimentary bed which has become lateritised.

In contrast to the discoveries considered in the preceding paragraph, the absence in the vast bulk of the high-level laterite of any relics of the amygdular contents of the Deccan basalts have long been a matter for comment. The indestructible nature of such geode materials as agate, jasper and crystalline quartz, and their abundance in

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[27] Newbold, J. A. S. B., 13, 996 (1844); Foote, Mem. 12, 205, 217 (1876).

the Trap, would lead one to expect their frequent occurrence in the overlying laterite. In explanation of this anomaly, some of the uppermost Trap flows may have been of a peculiarly dense nature and free from amygdales—and examples of such beds are not rare among the traps of today—or, as Foote has suggested, the water which percolated into the uppermost flow, unlike that which found its way into lower traps, may not have contained silica in sufficient quantity to form siliceous amygdales in the rock vesicles.[28] It would at any rate seem probable that only particular varieties of the Trap are capable of undergoing lateritisation. Otherwise we should expect the occurrence of laterite upon the Trap to be far more general than it is; the greater part of the Deccan Trap surface is, on the contrary, free from laterite.

The bedded basaltic Rajmahal trap of the Rajmahal Hills is also capped by laterite, which covers the highest plateau in the range, Mahuagarhi, 1,655 feet above the sea. Here the laterite, in places as much as 200 feet thick, slopes gradually from the western scarp of the hills, where it attains its highest elevation, down to the Gangetic plain on the east. As in many parts of the Deccan there is an apparent passage from basalt into laterite, but at the same time the latter rock when followed to the east is described as continuous with the Low-level laterite of Bengal, which is clearly of detrital origin; this supposed continuity, however, requires confirmation.

In many areas, such as Berar, faulting of some considerable magnitude seems to have taken place subsequent to the formation of the laterite, and from the mode of occurrence of the rock in Surat and the Rajmahal Hills, Fox concludes that it has been affected by recent subsidence in these areas.

The distribution and peculiar features of Secondary Laterite must now be considered. Secondary Laterite is nothing more than the reconsolidated debris of older laterite, mixed or not with material derived from other rocks. It may be deposited conformably with sedimentary beds and its presence indicates nothing more than a proximity to some occurrence of the Primary rock. It is but a particular form of the detrital debris which is being steadily carried down by water from the great laterite-capped plateaux into lower country to the north, east, south and even west, where its components become cemented by segregation and chemical changes. The result is a laterite which is nearly always more ferruginous than the Primary rock and often pisolitic. The further it lies from the parent occurrences of primary laterite, the more highly ferruginous and the less aluminous is it likely to be; bauxitic varieties of the detrital rock are in fact not common and are confined as a rule to the immediate neighbourhood of the Primary laterite from which it has been derived. The preponderating ferruginous constituents, being more liable to dehydration, are sometimes completely converted to hematite by long exposure. An appreciable percentage of silica, especially in the form of free quartz, is nearly always a sign that any particular sample of laterite is of secondary origin. Impure forms of the detrital rock vary

[28] Mem. 12, 203 (1876).

from quartzose laterite, siliceous laterite or lithomargic laterite, to lateritic sand and sandstone or lateritic lithomarge. Detrital accumulations of bauxite, according to Fox, usually show a conglomeratic structure.

Most of the Secondary Laterite of India is found in the low-lying coastal regions on the east and west sides of the Peninsula which it encircles in the form of an interrupted fringe. On the west coast it has not been observed in that part of the Konkan north of Bombay, but makes its appearance a little farther south between Bombay and Ratnagiri, and extends thence throughout large tracts of the low country separating the Western Ghats from the sea, as far as Cape Comorin. In many places it has been cut away by streams, so that the lower formations are exposed ; in parts of the country it appears to be wanting. Between Ratnagiri and Goa the rock forms a kind of plateau, having a general elevation of 200 to 300 feet above the sea, and terminating in cliffs which expose the trap beneath. The low plateau extends inland for 15 or 20 miles, and is cut through by numerous rivers and streams, in all of which the trap is exposed and is separated from the laterite layer by intervening lignite and clays of Tertiary age and previously described. Farther inland this laterite is found at a higher elevation than near the coast, so that the rock appears to have a low slope towards the sea ; in places it is conglomeratic. Its thickness of 35 feet at Ratnagiri is probably less than the average. Evidently the coastal plateau at one time extended much farther to the east and probably covered the whole of the country as far as the base of the ghats. South of Malwan, where the underlying rock is no longer trap but gneiss or some other metamorphic formation, laterite is extensivly developed. In Travancore it overlies fossiliferous Tertiary beds.

On the east coast of India laterite occurs almost everywhere, rising from beneath the alluvium which fringes the coast and sloping gradually upwards towards the interior. It is, as a rule, much less a massive formation than the rock of the west coast, is seldom more than 20 feet in thickness, and is often represented by a mere sandy or gravelly deposit not more than four or five feet thick. Where it is thicker, the lower portion usually consists of lithomarge produced by the alteration of the underlying rock. The laterite is frequently conglomeratic and includes large, rounded or sub-angular fragments of gneiss and other rocks ; good examples are to be seen at Trichinopoly, at many places near Madras such as the Red Hills seven miles northwest of the city, and around the detached hills northwest of Cuttack in Orissa. In the Madras area palaeoliths of human construction have been found in the laterite in considerable numbers ; these are chiefly of quartzite and evidently fashioned from pebbles derivd from rocks of the Cuddapah system. In Ganjam, the laterite is often only a few feet thick and gives rise to a somewhat barren red soil, lying upon decomposed and weathered khondalite.[29]

The fringe of laterite along the east coast is of very unequal width. In some places it stretches as a low broad slope for many miles from

[29] Gen. Rep., 1899-1900, p. 161.

the edge of the alluvium; in others it remains as isolated caps upon the older rocks. In some form or another it can be traced, with short intervals, from Cape Comorin to Orissa and thence northward through Midnapore, Burdwan and Birbhum along the western edge of the Gangetic and Mahanadi alluvium, to the flanks of the Rajmahal Hills where it is well developed, as already noticed.

Low-level laterite is not confined to the neighbourhood of the coast. It is frequently found over many parts of the country in patches which are rarely of large size and often show unequivocal signs of a detrital origin. It is found on the opposite side of the Eastern Ghats on the 800-foot plain of western Kalahandi. A small proportion of the laterite of the Central Provinces and Central India is of detrital origin. In the Seoni district of the former, although over 100 feet thick and capping a plateau 2,000 feet high, it contains in some places angular and sub-angular grains of sand evenly distributed through the rock and is sometimes conglomeratic with true pebbles, ¼ inch to 4 inches in diameter, of a similar or slightly more aluminous composition in a highly ferruginous matrix; underneath it is a sandy lithomarge.[30] This laterite is characterised by well defined vertical joints which often become gaping fissures. The laterite now hidden beneath the desert sand of Bikaner and Jodhpur in Rajputana is of detrital derivation, as is also that quarried in Belgaum.

Many deposits of lateritic appearance are more of the nature of ferruginous gravel. The small pisolitic nodules so characteristic of some forms of laterite, are found abundantly in the Older Alluvium of the Ganges valley and in many other superficial deposits in the plains of India; wherever they are sufficiently plentiful they are liable to become cemented with the accompanying sand and clay into a rock closely resembling laterite in many of its peculiarities.

In some cases, which are said to be rare but which may be more frequent than supposed, an accumulation of detrital laterite has fostered a superinduced lateritisation *in situ* of the underlying rock, the result being a cap of secondary, lying upon a layer of primary young laterite which passes down into the parent rock beneath. What appears to be the converse of such a sequence is seen in the Raniganj coalfield where Primary Laterite has every appearance of lying upon Secondary. The former includes numerous fine quartz grains around which the limonite has been deposited in the process of lateritisation. This rock is underlain by a still more siliceous, rubbly laterite, consisting of an aggregate of ferruginous pellets, ¼-½ inch in diameter, partially consolidated by a matrix of ferruginous sand or silt. This lower deposit shows every sign of being a detrital deposit and grades into a quartzose laterite in which angular to sub-angular grains of quartz form a large proportion of the rock and in which even pebbles of white quartz are frequent; in places this rubbly basal laterite passes down without a break into lateritic gravel or conglomerate. In many cases the angular fragments of quartz associated with the laterite of this area can be recognised as derived from quartz geodes

[30] Burton, Rec. 48, 204 (1917).

in the Deccan Trap.[31] The impression produced in the Raniganj area is that a Secondary lateritic deposit is undergoing re-lateritisation. Whatever the true explanation may be, the occurrence is an example of the intimate association of the two types, and emphasises the statement already made, that Primary laterite is the product of a process which is more a result of climatic conditions than of rock surface or stratigraphical horizon. It may affect the upturned edges of denuded schists, the eroded surface of granite or gneiss, or the natural undisturbed upper surface of a lava flow.

Although there are large quantities of bauxite of sufficiently high grade to be used in the manufacture of aluminium, such an industry has not yet been established in India, and transport costs have so far prevented its export for this or any other purpose. The small output of this mineral has up to the present been merely sufficient to meet the small demands of oil companies who make use of it in the purification of kerosene, of chemical companies for the preparation of aluminous sulphates, and of iron and steel companies for furnace linings. An outlet for this material as an abrasive and in the manufacture of calcium aluminate cement has been under consideration.[32] Some of the laterites of Bombay and Goa are sufficiently rich in manganese-ore, mostly psilomelane and wad, occuring in bands or patches, 25 feet or less in depth and varying in width from 4 or 5 to 100 feet; this ore contains about 50 per cent. of manganese.[33] On a small scale laterite—especially the detrital variety—has been used as a source of iron in several places. All over the Peninsula it is used as a building stone and in the construction of culverts; for these purposes it is much in request on account of the ease and low cost with which it can be cut into blocks combined with its property of hardening when exposed to the air. It has frequently been used in the construction of the old forts and temples in the country. In some places it is used as road-metal, but is not suitable for heavy traffic.

Laterite is also an important reservoir rock in the Indian peninsula. On the central parts of the laterite plateaux wells are sunk down to the top of the clay or lithomarge which almost invariably underlies the laterite and, although the water encountered therein may become almost exhausted at the end of the hot weather, it rises to the top of the well again soon after the commencement of the rainy season. Most villages on or near these plateaux, however, obtain their water supply from the springs which issue from the laterite capping all round the base of its scarp; the most important of these springs are perennial. Along parts of the Ganjam Malias, where it caps a 3,500-foot plateau, as well as in Sambalpur, high-level laterite provides the main water supply of the surrounding country, springs arising all along the lower edge of its outcrop.[34]

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[31] Gee, Mem. 61, 73 (1932).

[32] Rec. 70, 352 (1936).

[33] Rec. 60, 46 (1927).

[34] Gen. Rep., 1899-1900, p. 161.

In Burma, laterite of detrital low-level type is found in places on the edge of the alluvial tracts of the Irrawaddy and Sittang rivers in Pegu and Thaton, forming as usual a cap to other rocks and having a very low dip from the valley sides towards the river. There is a well marked belt of this rock along the base of the metamorphic hills east of the Sittang river, forming a plateau which rises 50 or 60 feet above the alluvium of the Sittang valley. At Shwegyin in south Toungoo it is quarried for use as a building stone and as a road-metal.[35] The laterite of these parts is described as forming the basement bed of the post-Tertiary gravels and sands, and laterite gravels, apparently derived from the denudation of the massive laterite, are largely dispersed through the older alluvial deposits. Elsewhere east of the Pegu Yoma laterite is generally wanting, but is more common along the western foot of these hills.

West of the Irrawaddy, in the Henzada district, Stuart records the presence of a gravelly rock, more or less consolidated and often lateritic, and older than the soft loose Plateau Gravel. The older rock has shared in the faulting and folding which have affected the Tertiaries of this area, and has been referred by Stuart to the top of the Irrawadian series, under which head it has already been mentioned.[36]

Some laterite is also found in Tenasserim, whence it extends into the Malay peninsula. In Amerhst it usually caps the Mergui rocks of the low ground and foot-hills near the coast, and is described as being in process of formation at the present day. It is also found in the flat country east of the Taungnyo range in association with local gravels and sand.[37] In Mergui it is found on low-lying flatlands at the foot of hills composed of the Mergui series, in places where the soil is waterlogged for part of the year ;[38] it occurs also at the debouchures of stream.[39] It is sub-Recent and Recent in age and, in spite of its low position, is said to be still in process of formation. It is described as the usual alteration product of the Merguis but sometimes occurring on the granite of the district, in one or two of the islands (Pulo, Raleigh, etc) ; in Medaw Island it lies upon basalt. Some of it is associated with lithomarges. Laterites are also found together with Recent conglomerates and are obviously of detrital origin.[40]

Laterite found in the Irrawadian sands of the Shwebo district in discontinuous beds of irregular thickness swelling sometimes to twelve feet, is extensively quarried and used for facing canal embankments and in the construction of bridges.[41]

Origin.—Leaving out of consideration for the moment the detrital form of the rock, the mode of origin of laterite is still a question which is not completely understood. Of the many explanations which

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35 Rec. 60, 302 (1927).
36 Rec. 41, 251-252 (1911).
37 Rec. 73, 67 (1938).
38 Rec. 72, 69 (1937).
39 Mem. 55, 33 (1930).
40 Rec. 38, 55, (1909).
41 Rec. 63, 30 (1930).

have been put forward regarding the origin of high-level laterite it is not proposed to give any detailed analysis. They are mainly of two classes, the one in favour of a formation *in situ* from the rock on which it lies, and the other upholding a sedimentary derivation. It is now generally admitted that the former is the more correct view; at the same time much of the high-level material is not without sedimentary characters which would have to be taken into consideration. That laterite could have been a marine deposit is so improbable as to be unworthy of further mention, and it is inconceivable that fluviatile deposits should be so broadly distributed and yet so thin.

We may begin our summary of the question with what may be looked upon as a definite fact, and that is the upward passage in many places of Deccan Trap into laterite. It is unquestionable, therefore, that much, at least, of the high-level laterite of the Indian plateaux has originated *in situ* and sub-aerially—that it is a residual product of the parent rock below, having no extraneous mineral constituent save water. Rock weathering has obviously been carried beyond the stage of kaolinisation. In the words of Fox, "The mineral silicates have been decomposed; the more soluble constituents, both crystalloids and colloids, have been carried away in solution or suspension. Negative and positive *sols* have each year been precipitating *hydrogels* of silicic acid and alumina; silicic acid with titanium oxide; silicic acid with ferric oxide, etc. Suspended matter, possibly as *gels*, has been deposited at the outer base of the laterite mass by the spring discharge water, as complicated bands of laminated lithomarge and ferruginous grit. Large quantities of ferric hydroxide have been forced to the surface from the upper portions of the laterite mass, possibly as a result of capillary pressures and surface tension as the level of the ground water slowly fell. The leached zone of bauxite has possibly acted as a semi-permeable membrane to the upward movement of the colloidal silica from below, or the return of the colloidal ferric hydroxide from above. These processes, if continued for vast periods of time, would result in the steady enlargement of the three horizons, the '*cuirasse de fer*' at the top, the bauxite immediately below, and the lithomargic material of the springs at the base of the laterite."[42] There is no evidence of any organic agency, and the decomposition of the mineral silicates appears to be due to percolating waters during the wet or rainy season.

The question next presents itself: was the Primary laterite of India derived entirely from the Trap? The evidence on this point is somewhat confused by the uncertainty in the case of some occurrences as to whether they are primary or secondary, and a re-examination of the outcrops in the south of the Peninsula is desirable. It has been shown, and was recognised long ago, that some at least of the laterite now found beyond the edges of the Trap outcrop once covered trap flows or beds, which have entirely succumbed to lateritising agencies. Is it permissible to go a step further and assume that all high-level laterite at one time covered a trap sheet, and that its present position

[42] Mem. 49, 39-40 (1923).

upon gneisses and schists[43] is merely due to the complete lateritisation of these trap sheets? In some cases it is claimed that there is just as gradual a passage down into schists or gneiss as there is elsewhere into basalt, and more than one writer has been forced to conclude that the laterite has resulted from the alteration *in situ* of such non-trappean rocks. Nonetheless it is difficult to understand how rocks so totally dissimilar in constitution as basalt and gneiss could have produced precisely the same rock by a simple process of disintegration *in situ.* How can the weathering product of a gneiss be of such a highly ferruginous character—more highly ferruginous in fact than the average trap?

At the same time, any theory based on the assumption that primary laterite is in every case derived from trap presupposes an enormous extension of the Deccan Trap area southwards and eastwards. Eastwards there is some incentive to concede such a possibility, if we accept the suggestion that the Rajmahal Trap was but an early phase of the Deccan outpouring; that there may have been a practically continuous outcrop of Trap between the Mandla district and the Rajmahal Hills is not a difficult supposition to accept. To the south, however, it would be necessary to presume that the Trap spread not only over at least parts of the Nilgiri and Shevaroy hills, but stretched probably as far as Ceylon. No trace of the trap rock has been reported from these southern parts, unless we assume the laterite itself, found on the Nilgiri, Shevaroy and other plateaux, to represent such a trace. Several writers have expressed a definite opinion that laterite in the strict sense of the term, has been produced by the surface alteration of rocks other than traps. One of the latest of these expressions is from the pen of Krishnan who finds reason to conclude that the laterite of the eastern Ghats has in many cases been formed by the superficial alteration of Khondalite.[44] If the more or less flat tops of the Mysore plateau and of parts of the Nilgiris, Shevaroys, Palanis and other so-called ranges, are the relics of a peneplain of marine denudation, they must date back to pre-Cambrian times, when this region was last beneath the sea, and it is easier to comprehend how such wide stretches of undissected tableland could survive so immense a period, if they were protected by a cap of laterite, or of some similar material. If the lateritic material had commenced to form soon after the emergence of this ancient peneplain, it might conceivably have done much to preserve plateau conditions; this of course is contrary to the idea that true laterite is peculiarly and almost exclusively Tertiary product.

From a study of laterite in many parts of the world the general conditions essential for its formation appear to be:

(i) a tropical climate subject to highly contrasted alternations of dry and wet seasons;

(ii) flat or very gently sloping, relatively elevated land-surfaces;

[43] The laterite resting on Vindhyan sandstone or Gondwana clays is all probably of detrital kind.

[44] Rec. 68, 392 (1935).

(iii) exposure of rocks of suitable chemical and mineral composition, and of a porous or finely jointed texture ; and

(iv) conditions favouring a seasonal alternation of water-logging and desiccation.

The last mentioned condition involves a rise and fall of the ground-water level between the wet and dry seasons. Each year, as pointed out by Fox, the weathered rock has been drenched by infiltrating water; each year also it has been drained and its inmost recesses infused with air. H. Warth has pointed out that the weather products of a basaltic rock exposed to a temperate climate differ essentially from those of the Deccan Trap under climatic conditions such as those which prevail in the Bombay Presidency.[45]

Howsoever laterite originated, time was certainly a factor in its formation, and the occurrence of beds of bole among the Deccan Traps suggests that the same causes which subsequently led to its formation, were at work during the Deccan Trap period, but that the succession of lava flows was sufficiently rapid not to leave them time to produce the full effect which resulted when the eruptions had ceased.

Without exception true laterite which has escaped folding movement, is found only on level or gently undulating surfaces, if we ignore the irregularities produced by subsequent denudation. It is found on the terrace bordering the sea coast, and on the plateaux capping the hills further inland, but never in its true form on the intermediate slopes. The rounded surfaces of the gneissic hills of Ceylon and southern India are often covered to a great depth with a more or less ferruginous sub-soil, which never passes into true laterite, except in such localities as the summit plateau of the Shevaroy hills, or the plain bordering the sea coast and now intersected with valleys of denudation.

Although Primary laterite is essentially a chemically formed rock, it is not without sedimentary characters which are more pronounced in some places than they are in others ; some of the thicker beds especially may show signs of sedimentation. The deposits in Balaghat and Jubbulpore, for instance, are described as often exhibiting well defined bedding.[46] Anyone who has watched the lashing of the surface of these comparatively barren or scantily forested plateaux by the torrential rain of the wet monsoon season, will not be surprised to find here and there in the laterite evidence of sedimentation and sorting action effected by rain-wash in innumerable small transient pools. In the vast majority of cases these thin layers of sediment would consist entirely of the aluminous and ferruginous material of the eroded laterite itself, but now and again in favourable positions grains of sand and small pebbles might well become involved in the formation of a rock which, in other respects, is of primary origin and formed in the immediate neighbourhood. Even the lithomarge sometimes has bands of gritty material, and shows a peculiar varve-like

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[45] Geol. Mag., Dec. 5, II, Jan. 1905.
[46] Rec. 32, 144 (1905).

though irregular lamination, so well seen in Fox's photographs (Mem. 49, pl. 5). In the numerous instances in which laterite, including the high-level variety rests upon a hard, clean surface of basalt or any other rock, with no signs of a passage from one to the other, the laterite must be looked upon as a sedimentary deposit laid down perhaps in a pool of greater size or permanence upon a surface which for some reason or other is not susceptible to lateritic change. The apparent lateral continuity between primary laterite and unquestionably detrital material is probably accidental in some cases and has been mistakenly identified in others; it has led to much dispute as to the origin of the rock. In most cases it is easy to distinguish between the two in the field.

Age.—There is no definite proof that lateritising processes had not functioned long before the Deccan Trap period; but the general opinion is that this peculiar surface alteration, so far as the vast bulk of the Indian deposits are concerned, began at some date subsequent to the termination of the volcanic outbursts. There is good reason to believe that it is still taking place[47] and that, whatever the date of its first formation may have been, lateritisation has been more or less continuous ever since. While material has been washed of its surface, freshly formed lateritic material has been added from below, transfusing and percolating upwards through the lithomarge. Therefore, although the *process* of lateritisation, which produced the deposits we are considering, may date from early Palaeocene times, or perhaps even a little earlier, it is improbable that any of this early formed material has survived, and the actual lateritic rock seen today on the Indian plateaux may be of much later date.

Beds of laterite are described by Blanfold as interstratified with the Nummulitic limestones and gravels of Gujarat and Cutch. Some at least of this rock is detrital in kind but, where exposed, it is seen to be a true laterite with excess of hydrated alumina and ferric oxide over silica. Similar beds have been noted among the early Eocene sediments of Jammu and the Salt Range. In Jammu the bauxite-containing formation, which rests upon 20 or 30 feet of a residual breccia derived from the underlying Great Limestone is described by Middlemiss as passing laterally into hard coal; the bauxitic formation comprises, besides bauxite, kaolin, ferruginous layers and rarely coal.[48] These old laterites are of special interest since they afford some evidence, though not entirely conclusive, of the early Eocene climate of India. If it is correct to conclude that a climate of alternative wet and dry seasons is essential for the formation of true laterite—and there is very much in favour of such a conclusion—and if at the same time we can assume that the laterite of Gujarat as it passes under the Eocene limestones persists in its true character and does not pass into a merely ferruginous band—an assumption for

[47] Dr. Fox deduces this from the relationships which appear to exist between the enrichments of bauxite and existing channels of underground percolation.

[48] Min. Surv. Jammu and Kashmir, 1928; see also T. V. M. Rao, Miner. Mag., 22, 87-91 (1929).

which the grounds are somewhat less reliable—it follows that monsoon conditions must have been established in India in Eocene times.[49]

The occurrence of laterite in the Indian peninsula in the form of a few isolated caps has been quoted as showing that it was once a much more extensive formation. This deduction has been criticised on the grounds that laterite might form independently on any flat-topped isolated hill. That it could do so and is in fact doing so today is indisputable, but there is no doubt that the beds of trap beneath the laterite on these isolated hills, once formed a continuous sheet and, this being so, it seems highly probable that the overlying ferruginous soil-cap did the same. Whatever the precise nature of the early Tertiary soil-cap may have been, it must have existed before the denudation of the area had much advanced, and began in all probability immediately after the last volcanic eruptions. True primary laterite, it is claimed, is the product of a monsoon climate, and cannot have begun to form until monsoon conditions had been established in India. If the early Tertiary ferruginous soil beds were true laterites, we should have to presume that monsoon conditions had been established in the Indian peninsula at the beginning of the Eocene epoch. Such a conclusion rests on inconclusive grounds, unless it be assumed that all ferruginous soils are exclusively the product of sharply contrasted alternating dry and wet seasons. Certain indications, as we have seen, favour the assumption that monsoon seasonal conditions came into being during the Siwalik period and, inconclusive though such indications are, there is no definite proof that the detritus which capped the Trap during the first half of the Tertiary period was anything more than a ferruginous soil which did not attain the peculiar composition of true laterite until the Miocene epoch when monsoon conditions appear first to have begun. This argument of course falls to the ground if it be held that the formation of primary laterite owes nothing to severe seasonal differences, but is essentially due to other causes, especially to the presence of a highly ferruginous and aluminous country rock such as basalt.

In places the Deccan Traps appear to have undergone extensive denudation before developing the layer of laterite which has capped them presumably ever since. In hills such as Matheran, for example,

[49] The fact that the true laterite is a rock which owes its essential pecularities to chemical changes weakens its value as a stratigraphical index. It is, for example, not impossible to suppose that the rock underlying the Nummulitic limestone of Surat was originally an ordinary ferruginous soil and that it has developed the peculiarities of laterite only in those portions exposed to the atmosphere and monsoon conditions of present-day India. It is underlain by Deccan Trap, from which its peculiar chemical components might have leached upwards in the way described by Fox. Whether detrital or not, the rock might not have acquired its truly lateritic character till much later in the Tertiary period. The question is of considerable importance since it raises a much broader issue. Is it possible that the Primary Laterite of the Indian plateaux originated as an ordinary ferruginous soil and only began to develop its peculiar bauxitic character when a monsoon climate, first became established? If so, we have no very certain grounds for concluding that monsoon condition obtained in India as early as the Eocene, and there is a possibility that the date may have been considerably earlier.

the uppermost trap bed is at least 2,000 feet below the highest volcanic flows of the neighbourhood, and the lateritisation which now characterises its surface must have begun after a considerable reduction in level by erosion.

Of the origin of Secondary Laterite little need be said for it is a purely detrital deposit. Its striking similarity to the primary rock in many cases is entirely due to the unusual capacity of the latter to become re-cemented after disintegration and transport. According to Fox, the boulders and nodules of laterite which roll down from the scarps of the primary rock consist usually of segregations of bauxite or aluminous laterite in a matrix of ferruginous material. While the bauxite nodules are generally tough and resist fracture, the ferruginous portions of the rock are comparatively soft when fresh, or powdery when hardened by exposure, and do not withstand mechanical impact to the same degree as the aluminous types. In this way the bauxite accumulations tend to concentrate within a short distance of their provenance, while the ferruginous material is carried to greater and greater distances.[50] In many cases these secondary bauxitic accumulations have a higher aluminium content than the primary laterite of the scarp from which they were derived. The re-cemented ferruginous matter may be denuded and redeposited further away again and again. Vast quantities have thus been washed into valleys and plains which have been subsequently dissected into more recent channels. The difference in age between Secondary Laterite and Primary lateritisation is in most cases shown by the smaller degree of denudation suffered by the former since its deposition. Nevertheless the denudation of these younger beds is by no means negligible. The plateau near the sea on the west coast near Ratnagiri and elsewhere has been cut through by streams to a great depth and the underlying trap exposed ; further inland, at a higher level, only a few caps of low-level laterite remain. On the east coast which, owing to the large amount of silt brought down by rivers is protected from the action of the sea, the lateritic deposits have suffered less denudation, in consequence of their being so frequently covered by later alluvial silt ; away from the coast it has been removed by erosion over large areas. Some "Karambar rings" or stone circles found between the two villages of Amarambedu (Amerumbode) and Madarpakkam (Maderapaucum), some 30 miles N. N. W. of Madras, are made of blocks of laterite.

There is every degree of transition between Secondary Laterite and lateritic earths and gravels with a ferruginous matrix ; the term, laterite, as already explained, has been loosely but widely employed for these ferruginous clastic rocks which are nonetheless without the essential features of true laterite.

[50] Mem. 49, 36-37 (1923).

CHAPTER XXXVII.

THE INDO-GANGETIC AND BRAHMAPUTRA PLAINS.

Extent. Absence of marine features. Classification. *Kankar.* Lithological character. Soil. Evidence of borings. Torsion Balance observations. "Spring-wells". Organic remains. Various aspects of the alluvial plain. The plains of the middle Ganges. *Bhabar* and *Tarai*. *Bhangar* and *Khadar* *Bhur* land. Assam. The Ganges and Brahmaputra delta. Salt efflorescence and salt lakes. Sambhar Lake. Lonar Lake. Sind and Khairpur. Reh in Burma. The Punjab, The lower Indus plain. The Thar or Great Indian Desert.

Extent.—The immense alluvial plain of the Ganges, Indus and Brahmaputra rivers and their tributaries including the richest and most populous portion of India, covers an area of about 300,000 square miles. The greater part of the provinces of Assam, Bengal, Bihar, the United Provinces, the Punjab and Sind, are included in the great plain which, varying in width from 90 to nearly 300 miles, entirely separates the geological region of peninsular India from the Himalayas and the Hazara mountains to the north, the Sulaiman and Kirthar ranges to the west, and the hill tracts of Assam, Tipperah and Chittagong to the east. Owing to the varying extent to which the surface is raised on the margins of the area by the detritus brought down by rivers from the hills, and the gradation between the finer deposits of the plain and the coarser gravels forming the slope, at the base of the Himalaya, it is difficult to estimate exactly the greatest height of the plain above the sea. The highest level recorded by the Great Trigonometrical Survey between the Ganges and Indus, on the road from Saharanpur to Ludhiana, is 924 feet, and this may be taken as the summit level at the lowest part of the ill-defined watershed between the Indus and the Ganges. There is no ridge of high ground between the Ganges and the Indus drainage, and a very trifling change in the surface might at any time transfer the affluents of one river to the other. There is little doubt, in fact, that such changes have taken place in past times. The following elevations above sea-level (in feet) will give some idea of the configuration of this great plain:

Brahmaputra valley		*Ganges valley*		*Indus valley*	
Sadiya	440	Burdwan	102	Ambala	901
Dibrugarh	348	Rajmahal	68	Ludhiana	806
Sibsagar	319	Benares	258	Ferozepore	645
Buramukh, near Tezpur	256	Allahabad	319	Lahore	708
Gauhati	163	Cawnpore	417	Dera Ismail Khan	595
Goalpara	150	Agra	553	Multan	407
		Delhi	715	Bahawalpur	375
		Meerut	739	Kashmir, Upper Sind	246
		Saharanpur	907	Shikarpur	198
				Sehwan	110
				Kotri	66

Absence of marine Features.—On the southern flank of the Himalayas, no marine formations have been observed of later date than Eocene, and this series is not found east of the Ramganga until we come to the Garo hills of Assam. In Sind marine beds of Miocene age are found, but they become replaced by fresh-water sediments as they are traced up the Indus valley, and in the Salt Range the fresh-water Siwaliks rest upon Nummulitic limestone. The amount of information derived from borings through the Indo-Gangetic alluvium is very small indeed but, so far as that information extends, and so far as the lower strata of this alluvial plain have been exposed in the beds of rivers, not a single marine shell has ever been observed outside the delta areas, nor is there any change in the nature of the deposits such as would render it probable that the underlying strata are marine. As will be shown presently, the lowest deposits known in the plain itself are of post-Tertiary age, and they are certainly fresh-water; the Tertiary deposits, as we have seen, occur chiefly along the northern margin of the plain. The fact that several species of mammals are common to the Siwalik deposits along the base of the Himalaya and to deposits of the same age at the southwestern end of the alluvial area, in Piram Island in the Gulf of Cambay, shows that there must have been land connection between the two areas.

The only marine features of the Gangetic alluvium are a few brine springs and a deposit of gypsum. The former are not numerous and cannot be accepted as proof of marine deposition as far as the alluvium itself is concerned. Gypsum in the form of selenite is found in the angle between the Betwa and its tributary the Bairma in the Hamirpur district of the United Provinces. The mineral occurs in several places some 4-6 feet below the surface, irrespective of the elevation or position of the locality, in the numerous ravines which fringe the high alluvial plain in the neighbourhood of the main rivers.[1] La Touche reports that it is entirely confined to the Older *kankar*-bearing alluvium and does not form a continuous band or even a succession of lenticular layers from one locality to another. As crystals and fragments it occurs in a plastic clay which is thought to mark the site of submerged springs—springs, that is to say, not powerful enough to flow out at the surface, but sufficiently so to keep the superficial layers of the alluvium in a more or less moist condition. Selenite is also found in the adjoining district of Jhansi, scattered, in a peculiar friable yellow clay. Another deposit of selenite has been noted on the left bank of the Ken river in Gaurthar State, to the south of Hamirpur. In Dholpur, the easternmost State of Rajputana, selenite is found in similar surroundings as imperfect crystals sparsely scattered in a carbonaceous layer some distance below the surface of the Older Alluvium. Here it is associated with the fresh-water mollusca, *Unio* aff. *corrugatus* Mull., *Corbiculla* aff. *occidens* Bens., *Melania tuberculata*, var., *Vivipara* sp., *Succinea* sp., and *Planorbis* sp., and appear to have been deposited during the desiccation of a small saline lake. Below the selenite-bearing band is a coarse sand.[2]

[1] Rec. 37 281 (1908).
[2] A. M. Heron, Rec. 45, 82 (1915).

Although it is practically certain that the sea never reached the upper tract of the Indo-Gangetic alluvial area after the Oligocene (topmost Subathu) period, it is possible that it covered portions of lower Sind on the one side and lower Bengal on the other long after the plain of upper India became dry land, though the actual evidence of such is in one case not conclusive and in the other more than doubtful. From recent changes in the delta of the Ganges and from historical data, it has been argued that practically the whole Ganges valley was probably uninhabitable 5,000 years ago, and that the extension of human settlements eastwards from the Punjab has been a slow and gradual process.[3] The Ganges valley 5,000 years ago may, like that of the Brahmaputra today, have been so swampy as to be ill-suited for cultivation, without being entirely uninhabitable. Be that as it may, swampy conditions afford no reason for supposing that any appreciable part of the area had recently been covered by the sea, for the state of the surface might have been due to an amount of depression sufficient to render the area marshy, but not enough to cause an inundation by the ocean beyond the outer portion of the delta. That depression has taken place in the delta is shown by the records of the Fort William borehole in Calcutta, to be described presently. The discovery of an oyster bed, six inches or less in thickness, and only about 5 or 6 feet below the level of Clive Street in the same city, has been adduced as proof of upheaval, since the altitude of this bed is one scarcely ever reached by the highest spring tides in the Hooghly river.[4] The bed lies on black mud or blue clay. The oyster, identified by Newton & Smith as *Ostraea* (*Crassostraea*) *gryphoides* Schloth, and a variety of the same termed by them *cuttackensis*,[5] is a robust form characterised by a long umbonal part and a long ligamental pit, so that the animal could raise its shell above the mud in which it would be otherwise buried; it is a large species living abundantly in the mud banks near the mouths of the channels of the Sunderbans. With it were found a number of other forms, both marine and fresh-water, which were determined by Annandale as follows:[6]

Telescopium fuscum Ch., essentially an estuarine form, common in Mangrove swamps, in the ditches around Calcutta, and living abundantly among the oyster banks in the Sunderbans;

Paludina (*Vivipara*) bengalensis Lam., one of the commonest fresh-water shells in Lower Bengal, and found sometimes in slightly brackish water near Calcutta;

Ampullaria globoso Swains, with the same habits as the preceding;

? *Aricia moneta* Linn., essentially marine, an inhabitant of clean salt water;

Planorbis exustus Desh.; one specimen only, a thoroughly fresh-water species, very common in ponds around Calcutta;

[3] Ferguson, Q. J. G. S., 19, 321 (1863).
[4] Rec. 31, 174-175 (1904).
[5] Rec. 42, 11 (1912).
[6] Rec. 37. 222 (1908); *vide* also Coggin Brown—J.A.S.B. 19, 76-77 (1923).

Anomia achoeus Gray; a common species in the estuaries of the Ganges;

Arca adamsiana Dkr., a single specimen;

Ostraea cucullata Bow., common in brackish water;

Balanus patellaris Spengler;

Lepralia (Escharioides) occlusa Busk, var.; the species found in N. Australia and the Philippines.

Serpula tubes.

Fragment of a carnivore bone, probably of a large wolf or dog.

Elephant bones, probably of the living *Elephas Indicus*.

Vivipara bengalensis, the dominant species of *Vivipara* in the present Ganges valley, according to Annandale, has many races and phases in different parts of the plains of India west of the Indus;[7] the series from Clive Street is one of thin and small forms, representing a type by no means uncommon in ponds of very slightly brackish water in the Ganges delta. The marine conditions deduced from the character of this assemblage have been challenged by Messrs. Newton and Smith, who explain the mixture of marine, estuarine and fresh-water forms by adopting a suggestion of Col. H. H. Godwin-Austen, *viz.*, that the oysters and specimens of *Telescopium* were brought by human agency to Calcutta in native boats and dumped on the site of Clive Street for the purpose of lime-burning. In this connection, it may be remarked that the doubtful specimen of *Aricia noneta* was very much worn, and is a shell which was at one time used as money in Lower Bengal; its presence in the deposit, therefore may be purely adventitious. That large shells such as the *Ostraea* and *Telescopium* mentioned have been collected and used for lime-burning is a known fact, and the discovery in further excavations in Swallow Lane, Calcutta, of cinders and broken pottery among the oyster shells, some 5 or 6 feet below the road-level, justifies the definite conclusion that the marine shells and the accompaniments just mentioned were deposited on their present site by human agency in comparatively recent times. The older theory that the deposits immediately underlying Calcutta are of fresh-water or estuarine origin without any traces of marine sediments, therefore stands.[8] We know that as late as Lower Miocene times the sea covered parts of Mayurbhanj and extends as far north as the Shillong plateau of Assam. That there has been a general southward retreat of the sea since that date is equally certain and, if that recession were regular and uninterrupted, it follows that in Pleistocene and early Recent times its waters must have stretched a little farther north than they do today and have covered what is now the lower part of the Ganges delta. Any direct conclusive evidence of this, however, there is none.

Of the sea ever having occupied part of the Indus valley in post-Tertiary times, evidence is also scanty. The Salt lakes of Umarkot

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[7] Rec. 51, 365 (1920).
[8] Rec. 56, 21 (1924).

in eastern Sind do not, as we shall see (p. 2001), necessarily prove the existence of marine strata beneath the soil on which they lie; the only indication that these lakes may have been in recent communication with the sea is the presence of an estuarine gastropod, *Potamides* (*Pirenella*) *layardi*, which is common in the salt lagoons and backwaters of the Indian coast. Umarkot is not much more than 70 miles from the Great Rann of Cutch and, as already shown, both the present condition of the Rann and tradition point to the area having been covered by the sea in recent times and filled up by deposits from the streams emptying into it; the sea, therefore, may well have extended up into the southerly portion of the Thar or Great Indian Desert, at least as far as Umarkot in recent times. It has already been shown that the ocean covered considerable portions of Sind and southern Baluchistan in late Tertiary and early Pleistocene (Villefranchian) times, a persistence of marine conditions which does not appear to be paralleled in the lower Ganges valley where, from negative evidence, the retreat of the sea seems to have occurred earlier in the Tertiary period.

Classification.—The various silts of the Indo-Gangetic plain may be roughly classed under two subdivisions, Older and Newer Alluvium,[9] the former consisting of beds which are undergoing denudation, the latter of flood and delta deposits now in process of formation. It is almost impossible to draw any distinct line of separation between these two subdivisions, except in the rare cases in which they contain fossils. Generally speaking, all the relatively higher ground is composed of the older deposits, whilst the Newer Alluvium is chiefly confined to the neighbourhood of the river channels except in the Ganges delta and the Brahmaputra plain. There are large portions of both the Indus and the Ganges plains which are flooded every season, and on these areas newer deposits are laid by the flood waters; on the other hand, since the rivers are constantly changing their courses, they often sweep away deposits only a few years or even only a few months old.

In the Indus valley the alluvial silts are much more sandy than in the Ganges valley, and the surface of the ground is paler in colour except where marshy conditions prevail. The deposits of the Brahmaputra valley in Assam are also sandy. In both the Indus and the Brahmaputra valleys the greater part of the area is occupied by the Newer alluvial deposits, whilst the major portion of the Ganges plain, except towards the delta, is composed of the Older alluvial formation.

"Kankar"[10].—The prevailing form of silt throughout the Indo-Gangetic alluvial area is some kind of clay which is more or less sandy. While the older deposits generally contain *kankar*, the newer as a rule do not, but there are numerous exceptions in both cases. To dwellers in India *kankar* is a familiar term. Used originally to

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[9] See Manual, 2nd Edit., p. 430 (1893); Manuscript reports by W. Theobald; Rec. 3, 17 (1870); Medlicott. Rec. 6, 9 (1873).

[10] See the account of *Kankar* in the Jamuna alluvium by Capt. E. Smith; J.A.S.B., 2, 622 (1833); also Newbold, Journ. Roy Asiat. Soc., 8, 258 (1846).

the same character from top to bottom, *viz.*, alternations of sand and sandy silt with occasional bands of *kankar*, and beyond the mention of coarse sand near the bottom, there are no signs of an approach to the base of the alluvial deposits. Like all the other boreholes, it was sunk in search of an artesian supply of water and, apart from its interest in demonstrating the great thickness of the alluvial deposits, it is important as proving that artesian conditions do prevail under the Indo-Gangetic plain. Down to 400 feet all porous beds appeared to be saturated with water.[24] Between 400 and 750 feet no water was ecountered. At 750 feet water rose to within 13 feet of the surface, at 783 feet to within 9 feet, and at 975 feet to within 2 feet. Further down it sank slightly but at 1,189 feet water flowed from a bed of quicksand at the rate of 10 gallons per minute over the top of the casing which was 26 feet above the level of the river Gumti. The quality of the water was excellent but the supply insufficient for the requirements of the town.[25]

The Agra borehole, which was sunk near the southern margin of the alluvium and failed to obtain artesian water, is the only one which traversed the whole thickness of the beds and reached the supporting floor of rock below. The total thickness of alluvial deposits passed through was only 513 feet, composed of sand and sandy clays with frequent layers of *kankar* ; below this depth the boring penetrated 132 feet into Vindhyan strata, and it may have been these beds which yielded water highly charged with salts of magnesium and unfit for drinking purposes. The bottom of the alluvium at Agra is only 5 feet above sea-level, a fact of considerable interest when it is remembered how close the locality is to the edge of the alluvial basin.[26]

Ambala is on the watershed between the Jumna, which flows into the Ganges, and the Sutlej, a tributary of the Indus. There is very little of interest in the borehole put down between 1869 and 1872 at this locality, which is about 905 feet above the sea and 20 miles from the base of the Himalaya. The depth to which it was carried, 701 feet, was insufficient to demonstrate the total thickness of the alluvial deposits, and it ceased 200 feet above the level of the sea.[27] No mention is made of any organic remains being found. A second boring for water in the same town in 1925-1927 reached a total depth of 1,612 feet but failed to find artesian conditions.[28] The strata passed through, which gave great trouble by reason of their incoherence, consisted of alternations of sand and clay, both types calcareous in beds usually from 40 to 50 feet thick. Most of the beds contained both types in varying proportions, and bands of gravel were occasionally met with. The thickest bed of sandy material, 85 feet, occurred between 1,010 and 1,095 feet, the thickest bed of clayey material, 135 feet, between 415 and 520 feet. From 855 to 940 feet there was found a thick bed of calcareous clay. At about 400 feet the boring passed

[24] Mem. 32, pt. 1, 31 (1905).

[25] Rec. 23, 261 (1890).

[26] Rec. 18, 121 (1885); Mem 32, 39 (1905).

[27] Rec. 18, 121 (1885); Q.J.G.S. 28, 198 (1872).

[28] E. L. G. Clegg. Rec. 60, 303 (1927).

through gravels whose pebbles consisted mainly of quartz. The sands met with were micaceous, varying in texture from fine to coarse and were of a pepper-and-salt colour; the clays varied from buff to red ochre.

The Bhiwani boring in the Hissar district of the Punjab, situated on the Aravalli watershed is 3¾ miles E.N.E. of the granitoid gneiss of Deosir hill, 14 miles E.S.E. of Tosham with its schists and granite, 13 miles east of Nigana which stands upon granite, and 15½ miles N. by W. of Kaliana formed of schists and quartzites. The elevation of the locality is about 720 feet, and the depth of the unsuccessful boring was 431 feet. The material penetrated consisted of sand, some of it fine and earthy and some of it coarse, but all of it more or less cemented into a calcareous mass by the infiltration of carbonate of lime; in some places harder concretionary nodules of the same material were encountered. The absence of any clay deposit, as well as of any of the coarser forms of detrital material thruoghout so thick a section in such comparative proximity to exposed masses of rock, is remarkable.[29]

A boring in the grounds of the Khalsa College of Amritsar reached only 215 feet, but at 60 feet a supply of water was struck which was constant though not under pressure.[30]

The boring at Sabzalkot in the Dera Ghazi Khan district, 28 miles west of the Indus, is at the foot of a long slope and only four miles from the base of the hills. At this locality, which is about 400 feet above sea-level, a plentiful supply of slightly brackish water was met with from a boulder bed at a depth of 574 feet. By far the greater portion of the beds pierced consisted of sand and pebbles, clays being very subordinate.[31]

Torsion Balance observations.—Torsion Balance surveys by the Punjab Irrigation Department in front of the Salt Range show that the scarp of this range declines to a depth of from 4,000 to 5,000 feet within a few miles. The Sargodha inliers of Delhi and Aravalli rocks, forty miles south of the range, are revealed as summits of deeply buried hills.

"Spring-wells".—Mention may here be made of the innumerable shallow so-called "spring wells" sunk all over the Gangetic alluvium. In this alluvium are thick lenticular beds of impervious indurated clay, known in the United Provinces as *mota* and having no great lateral extension. The beds may occur at a depth coinciding with the level of permanent saturation or else 10, 20 or more feet beneath it. When such a clay bed occurs at an accessible depth, a well, if needed, is sunk to the upper surface of the clay bed and lined with masonry to keep the water-saturated sands above the clay from being washed into the excavation. The clay is then pierced by a narrow shaft, when water charged with sand and under a hydrostatic pressure proportional to its depth below the level of

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[29] Rec. 14, 235-236 (1881).
[30] Rec. 60, 99-100 (1927).
[31] Rec. 14, 236-237 (1881).

country to the westward of the Bhagirathi and Hooghly, and probably owes its comparative elevation to the deposits of the Mor, Adjai and Damodar rivers.

In the sea southside of the middle of the delta there is a singularly deep area, known and marked on charts as the " Swatch of no ground". This remarkable depression, marking an almost sudden change in the soundings from 5 or 10 fathoms all round to 200 and even 300 fathoms, runs N.N.E.-S.S.W. and may be a scouring effect of the strong currents engendered by the meeting of the tides from the east and west coasts of the Bay of Bengal.[51] A very similar depression exists in the bed of the shallow sea off the Indus delta and has probably originated in the same way as a result of a deficiency in sedimentation. The plumb-line shows a strong deflection towards the Swatch of no ground.[52]

Salt efflorescence and salt lakes.—The fertility of many large tracts of land in the Indo-Gangetic alluvial plain is destroyed or seriously affected by an efflorescence consisting chiefly of sodium carbonate (*Sajji*), sodium sulphate (*Khari*) and sodium chloride (*nimak*), with small quantities of magnesium and calcium salts. It is not seen in the damper regions such as Bengal but is found in the drier parts of the alluvial belt, especially in the Punjab. A general term for this crude efflorescence is *kalar*. In most places the carbonate predominates, and the term *reh* is, strictly speaking, more properly applied to such salt.[53] The terms *reh* and *kalar* are now very commonly used for the crude salt, whatever its composition may be, and have a merely geographical distinction, *reh* being employed in Bihar and the United Provinces, while *kalar* is used in the Punjab and Sind. *Sajji matti* is a more definite term for material in which the carbonate predominates, while *khari matti* is used for material whose main constituent is the sulphate. The word *usar*, meaning " barren " is commonly applied to land affected by this surface incrustation.

The *usar* plains have been in existence for centuries past. Where the salt is abundant, the water in the upper stratum of the alluvium becomes impregnated to an extent that is productive of serious injury to the health of the people who have to drink it. To a greater or less extent this pollution of the water near the surface is general throughout upper India, and the whole desert region from the coast of Cutch and Sind northwards and north-eastwards to the borders of the Delhi

[51] It has been suggested by Addams Williams that the 'Swatch' represents that portion of the sea floor over which the delta plinths advancing from the east and from the west have not yet met. This suggestion is difficult to accept as the sole cause of this steep depression, in view of the narrow width of the latter. Although recognisable over a length of eighty miles or so, it is scarcely over more than 8 or 12 miles across. If it were no more than a gap in the delta, it is difficult to understand how it could have persisted far so long without becoming long ago filled up (Report, Hooghly rivers, etc., Calcutta, p. 141): *vide* also two courses of six lectures by the same authority on the Ganges Delta delivered at the Bengal Engineering College of Sibpur in March, 1913 and March, 1920.

[52] Rec. 43, 150, Note 4 (1913).

[53] Rec. 6, 12-13 (1873).

district and Bhawalpur State are impregnated with salt. As far north as the Chhachh plain, to the north of Campbellpur, patches of this efflorescence are to be found. In many areas of internal drainage such as at Sambhar and Didwana in Rajputana, temporary salt lakes of some size have been produced and are exploited for the common domestic chloride salt; in other places sub-soil brine is raised for the same purpose, as at Pachbadra.[54] The innumerable *dhands* or salt pools of Sind and Khairpur, utilised for their content of carbonate, are manifestations of the same saline phenomena and must also be considered in this category.

Various explanations of the origin of this efflorescence and of the salt lakes and pools of Rajputana and Sind have been advanced, and more than one hypothesis seems applicable. The subject cannot be discussed here in detail but observation and experiment tend to show that the different constituents of the salt may to some extent at least, have originated in different ways and from different sources.

It is generally agreed that the salt, which is the result of accumulation by evaporation in a water-logged land, has not, to any but a negligible extent, been derived from underlying Tertiary rocks. It is not definitely impossible that some salt may be brought by underground channels from the Punjab Salt Range into parts of Rajputana, but the salt lakes of Sambhar, Didwana, Kachor-Rewassa, Degana and those near Kachawan, all lie within the impervious area of the Aravalli schists and at comparatively high levels, and the conclusion of Holland and Christie is that none of the water in these basins can have come from the irrigated lower levels of the Punjab.[55] In any case the fact that sweet water can be obtained by sinking shallow wells on *reh*-covered tracts proves that the impregnation persists to no great depth and has resulted from the top layers of soil becoming charged by capillary transference of saline solutions from the lower layers. Furthermore, the alluvium beneath the soil and the Tertiary rocks below the alluvium are demonstrably of fresh-water origin.

One of the earliest views, put forward by Center,[56] was that the formation of *reh* or *kalar* is the result of the decomposition of the ingredients of rocks and soils constantly going on under the influence of air and water. Undecomposed mineral fragments occur in the alluvial clays and silts themselves and on weathering liberate salts of sodium, magnesium and calcium. The amount of salt originating in such a direct way from soil constituents is probably much less than that brought into the soil by river water and derived from the vast exposures of schists, igneous rocks and argillaceous sediments drained thereby. All soils thus contain some salt and all water draining therefrom must be contaminated to a certain extent. According to this hypothesis, *reh* or *kalar* is a refuse product made up of such substances, which result from the various processes involved in the decomposition of rocks or rock detritus and in the formation of soil, and which have not been assimilated by plants. Unless these salts

[54] Rec. 70, 289 (1935).
[55] Rec. 38, 161 (1909).
[56] Rec. 13, 253 (1880).

are removed they cannot accumulate. The normal process of removal is obviously the percolation through the soil of rain-water which carries off any injurious excess of the rejected salts. If the amount of water be sufficient and through drainage exists, there will be a constant dilution and renewal of the sub-soil water. If, on the other hand, the water reaching the sub-soil can be dissipated only by evaporation during the dry season, salts will accumulate in such sub-soil water, and as this water is brought by capillary action to the surface and evaporated, the salts in solution will be deposited in the form of an efflorescence on the surface of the ground. La Touche finds the peculiar conditions of the *reh* country as regards drainage and evaporation a simple and sufficient explanation of the presence of the salt, and compares the process with that which, by universal assent, accounts for the presence of the salt in the sea.[57] It is worthy of note that the proportion of sodium sulphate and sodium chloride relative to each other in *reh* is in very many cases much the same as it is in the river and canal water from the Ganges and Jumna, *i.e.*, in water brought from the mountains whose detritus forms the plains of India.

The relative proportions of the chemical salts, however, vary enormously, as a perusal of the many analyses carried out by Cotter in the case of efflorescences and brines from Sind will show. So far as the solid efflorescences are concerned, these proportions appear to be largely determined or affected by the relative solubilities of the constituents; it was found, for instance, that the proportion of carbonate to chloride in the lake brines is much lower than it is in the efflorescence—an expected contrast due to fractional crystallisation in the latter whereby a large part of the chloride stays in solution.[58] Specimens of the efflorescence from the same locality of Parantij in Ahmedabad differ widely in their relative carbonate and chloride contents.[59] Samples from Cawnpore recently on sale in Calcutta were found to contain 27.02 per cent. of Na_2CO_3, 4.28 per cent. of $NaHCO_3$ and 33.98 per cent. of Na_2SO_4, while salt from Dehra Dun showed 31.44 per cent. of Na_2CO_3 and 6.55 per cent. of $NaHCO_3$.[60] Analyses of *reh* from the *usar* lands in the United Provinces have been carried out by J. L. Leather.[61]

According to Center, the sodium carbonate is derived from felspar acted upon by water carrying CO_2 in solution. A comparable suggestion has been made by F. W. Clarke with regard to the alkali in the similar efflorescence found in Nevada, *viz.*, that it represents a concentration of material leached from the igneous rocks of the neighbourhood.[62] A similar explanation has been advocated by La Touche & Christie in their account of the alkaline lake of Lonar in Berar.[63] There are, however, good grounds for concluding that the carbonate

[57] Mem. 35, 42 (1902).
[58] Mem. 47, 275 (1923).
[59] Rec. 68, 243 (1934).
[60] Rec. 64, 432 (1930).
[61] "Investigation on *Usar* Land in the U.P.", Allahabad 1914 ; see also Agric. Ledger, No. 5 (Reporter on Economic Products, Calcutta, 1902).
[62] "The Data of Geochemistry" ; Bull. U.S. Geol. Surv., No. 616 (1916).
[63] Rec. 41, 266 (1911).

has originated directly from the sulphate by the action of organic matter such as algae. Such a suggestion was made by Sickenburger in a paper dealing with the alkaline lakes of Egypt in which algae are abundant,[64] and was adopted by Holland & Christie in their investigations of the Rajputana salt deposits. They suppose the sodium sulphate to have been reduced to sulphide by the decomposition of organic matter which, chiefly in the form of algae, abounds in the Sambhar Lake after the rains and gives it a reddish tinge. "The sodium sulphide is then acted upon by the carbonic acid of the atmosphere, reinforced by that liberated by the decomposition of the algae, and sodium carbonate is formed, the sulphuretted hydrogen given off being doubtless to a great extent responsible for the intolerable stench prevalent at Sambhar when the lake is drying up. The intense blackness of the lake mud is also due to sulphuretted hydrogen, black ferrous sulphide being formed from the iron compounds in solution and suspension."[65] Cotter arrived at a similar view after studying the salt pools and lakes of Sind, the alkaline varieties of which also have a peculiar and offensive smell. The limited and capricious distribution of these alkaline lakes within a region of the ordinary variety of salt lakes predisposes one to accept such a conclusion, which is further supported by the presence of bacteria of a peculiar type in the alkaline lakes as well as by the very dark colour and carbonaceous appearance of the soil tapped by the percolating water which feeds the lakes.[66]

Center, in his theory, found it difficult to account for the presence of such a large proportion of chloride, and in this we cannot invoke comparison with sea-water which must have derived its chloride mainly from actual chloride deposits such as rock-salt. The quantities, in Rajputana especially, are far too great to be due directly to rock decomposition within or even without the area. In the more widely distributed rock minerals the proportion of chlorine is extremely small, and that the chlorides in *reh* could have been derived solely from the disintegration of such rocks is not credible. To account for its abundance Holland & Christie have adopted and elaborated a suggestion made by La Touche, who invokes a reverse process to that by which salt is carried to the sea by rivers draining the land, and puts forward the idea that the salt has been brought back to the land from the sea by the aid of wind.[67] Strong winds from the southwest blow across the salt-incrusted region of the Rann of Cutch during the months of April, May and June. That they are strong enough to carry small particles far inland is proved by the occurrence among the fragments of carbonate of lime in the desert sand 40 miles northeast of Bikaner and 500 miles away from Cutch of wind-blown foraminifera resembling those in the Tertiary rocks of Cutch; as we

[64] Chem. Zeit., 1892, pp. 1645-1691.

[65] Rec. 38, 167 (1909).

[66] Mem. 47 279 (1923).

[67] The aeolian origin of salt deposits was suggested as early as 1877, by F. Posepny in a paper on the salt lakes of the western states of America. (Sitz, b.d.k.Akad. Wien, 179, 1878).

have already seen also, wind-blown calcareous rocks, largely composed of foraminifera, are known in Kathiawar.[68] Salt is lighter than grains of quartz sand or carbonate of lime, and its tendency to form "hopper-shaped" crystals, as Holland & Christie point out, render it more likely to be lifted by the wind. Furthermore, fine drops of sea spray become quickly evaporated when rain does not accompany the wind, and the residual particles of salt are probably transported even more easily than the spray. Crystals of salt up to ¼ inch in diameter are known to have been lifted and carried a thousand yards by the wind at Sambhar. In the desert, away from the Sambhar salt works, it is said to be possible to taste the salt on one's lips, while the dew on the *faras* trees, according to E. D. Nunn, is distinctly saline. Samples of rain-water collected at the beginning of the Rains from Jaipur, Sambhar, Bikaner, Ajmer, Jodhpur, Pachbadra and Udaipur, have yielded unusually high percentages of chlorine. The question has been placed beyond all doubt by a series of determinations carried out by Sir Thomas Holland and W. A. K. Christie of the amount of salt held in suspension by the winds which reach the Sambhar area from the southwest. After making certain assumptions based on these experiments and on known facts, they found it possible to conclude that the amount of salt transported into Rajputana by the wind each hot weather might well be of the order of 130,000 tons. It would not be an overstatement, therefore, to say that the quantity of salt carried by the southwest wind into Sind and Rajputana would account for practically all the sodium chloride impregnating the soil throughout the desert region; by the monsoon floods this salt would be washed into local depressions to form the numerous salt lakes.

This statement might be extended with safety to the Punjab, probably to the United Provinces and perhaps to Bihar as well—to any portion, in fact of the Indo-Gangetic plain with a sufficiently dry climate, for it must not be imagined that the particles of salt reach their destination in a single journey. The latter is performed in innumerable stages up from the Arabian Sea, the particles falling every now and then on to the desert surface to be whirled aloft by the next gust of wind; in many cases they would pass through stages of solution in rain or surface water, recrystallisation by evaporation, and a resumption of their aeolian course north-eastwards. Whether the chloride in the Lonar Lake of Berar owes its presence to such a process is not beyond the bounds of experiment similar to that employed in the case of Sambhar, and is by no means improbable.

In the case of upper India it is easy to understand how the destruction of conditions necessary for cultivation has been established, and it is not improbable that the Thar or Great Indian Desert owes its gradual formation chiefly if not entirely to the salt blown up from the Arabian Sea and the Rann of Cutch, for it stretches as a broad belt in the track of the wind from southwest to northeast, from the coast to the southern edge of the Punjab. A brine-impregnated subsoil exists throughout this desert region. North of Rajputana this sub-soil brine is raised and evaporated for salt in the districts southwest of Delhi, while to the northwest saline soil are common in

[68] Q.J.G.S. 56, 563 (1900).

Bhawalpur State and in the Punjab districts of Multan and Muzaffargarh. Shallow wells sunk in the sand in most parts of Rajputana are brackish.

The plains of upper India, as well as the desert, include large stretches of treeless country. For a great part of the year a scorching sun and a parching wind dry up all moisture in the ground, rendering it hard and impervious. When the rains of the monsoon season fall, a large proportion of the water runs off the surface into streams and the earth is unable to absorb more than a portion of what remains. In this way a large proportion is evaporated without penetrating the ground. The little that does percolate through cracks and occasionally more porous layers to the upper water stratum, is no more than sufficient to replace what has been dissipated by evaporation fed by capillary action.

This more or less complete want of water circulation in the sub-soil must have been gradually producing its effects in upper India throughout many generations. The natural infection is so slow a process that it would escape notice were it not for the fact that from time to time larger tracts of land become barren. The contamination is unfortunately carried further afield by rivers and canals. The immediate effect of the large irrigation canals, for instance, is to raise the level of the *reh* polluted sub-soil water, and thus to cause a great increase of evaporation, with the result of more *reh* being left on the surface and more land being thrown out of cultivation. All canal as well as river water contains salts in solution and the effect of canal irrigation upon undrained water-logged areas must be a contribution of salt, unless facilities for the drainage of the sub-soil water are provided at the same time; in this way additional *usar* land has resulted within the last few decades. The remedies are: (*i*) the cultivation of plants which assimilate a large amount of these salts; (*ii*) the application of suitable mineral manures so as to facilitate the utilisation of the salts by ordinary crops; or (*iii*) the application of efficient drainage. The last is the only really effective remedy where there are inexhaustible and ever-renewed sources of salt in river or canal water. The source of the *reh* of Parantij in Ahmedabad is thought by P. K. Ghosh to be the waters of the rivers Bogh and Khari.[69]

Deleterious as it is from an agricultural point of view, *reh* is employed for industrial purposes and the annual production and even export in one form or another are considerable. *Sajji matti*, the variety in which the carbonate predominates, is recovered in many parts of the United Provinces and can be used either for soap making or directly for laundering clothes; it has been estimated that from the United Provinces alone crude soda equivalent to at least 4 million tons of Na_2CO_3 could be collected annually from the surface of the ground. *Khari matti*, in which sodium sulphate is the most plentiful constituent, is the prevalent variety in Bihar. It is used chiefly by tanners for preserving hides and has the reputation

[69] Rec. 68, 243 (1934).

of producing a softer leather than treatment with pure materials;[70] it is also employed as a cathartic for cattle, and by the tea-planters of Bihar for cooling drinking water.[71]

Sambhar Lake.—The Sambhar Lake, draining by means of four main rivers and other smaller ones a catchment area of about 2,200 square miles of sandy and sterile country, is situated partly in Marwar and partly in Jaipur, in the centre of a closed depression in the Aravalli schists. Blown sand may have had much to do with the formation of the closed drainage of this and other areas, but the subject does not seem to have received much attention. The Sambhar Lake is the most important of the salt lakes of Rajputana, and is the centre of an active salt industry. When at its highest level, the lake covers an area of some 90 square miles, but dwindles to a small central puddle by March or April. Throughout most of the year, therefore, the depression is almost devoid of water, but in seasons of normal monsoon rainfall, the depth of water in the middle of the lake averages about four feet;[72] the depth of saliferous silt in the centre is 60-70 feet, with an average percentage of NaCl of 5·21 throughout the uppermost 12 feet. As the lake dries brine rises by capillarity to the surface and is evaporated to dryness, and the layer of salt thus produced is ready for rapid solution by the monsoon rains.[73]

The following analyses of Sambhar Lake brine and of sea-water show that the place of magnesium, calcium and potassium in the sea-water has been taken by extra sodium in the lake brine, and that some of the chlorine of the sea-water is represented in the lake brine by more sulphate and carbonate.

	Sambhar Lake. (W. A. K. Christie).	Ocean. (W. Dittmar).
Na	38·86	30·593.
K	0·09	1·106.
Ca	trace	1·197.
Mg	0·01	3.725.
Cl	52·96	55·292.
SO_4	5·85	7·692.
CO_3	2·19	0·207.
Br	0·04	0·188.
	100·00	100·000

[70] Rec. 64, 433 (1930).
[71] Rec. 53, 300 (1921).
[72] Rec. 38, 155 (1909).
[73] Rec. 70, 289 (1936).

The uppermost 12 feet of saline silt in Sambhar includes 55 million tons of sodium chloride, and it is this constituent which is exploited and won from the brine; after its extraction the mother liquors contain a high percentage of sulphate and carbonate and are a potential source of these salts. The dried residue in the lake contains about 86 per cent. of NaCl. Other smaller temporary salt lakes in Rajputana are those of Didwana, Falodi, Lonkara-Sur and Kachor-Rewassa, and a brine-impregnated soil stretches throughout this desert region from the Rann of Cutch up to the districts southwest of Delhi. Large quantities of ordinary salt are obtained from brine pits situated in various depressions in the general surface of the plain of western Rajputana the largest of which occurs near Pachbadra (Pachpadra; Panchbhadra). Pachbadra which is about 100 miles from the Rann of Cutch, and only some 400-500 feet above sea-level, is outside the Aravalli schist belt. The average yearly output of ordinary chloride salt from Sambhar is something like 240,000 tons; much smaller quantities come from Pachbadra and Didwana. North of the Rajputana country sub-soil brine is raised and evaporated for salt in a cluster of villages in the Sultanpur *mahal*, southwest of Delhi. Other places occur in parts of the United Provinces and in Berar, where large quantities of salt were formerly obtained from sub-soil brine in the alluvium of the Purna river. In Gwalior State salt is regularly manufactured from sub-soil brine.[74]

Lonar Lake.—Although situated within the Deccan Trap area, many miles away from the Indo-Gangetic alluvial tract, the curious crateriform hollow known as the Lonar Lake, a description of which has already been given (p. 1373), is characterised by saline contents comparable to those of the Sambhar Lake. This lake lies near the southern border of the Buldana district of Berar; from its shallow sheet of brine, which in the dry season is never more than two feet deep and is surrounded by a ring of thick black mud, products of varying degree of purity are recovered by crude fractional crystallisation, the most useful, *dalla,* having a composition approaching that of ureo,[75] $Na_2CO_3.NaHCO_3.2H_2O$; admixed with the latter is some sodium chloride. This deposit has evidently been formed by evaporation of the stream water in the absence of an exit.

This spasmodic industry has existed for centuries. La Touche and Christie consider that the chloride is probably derived to a considerable extent from the sea[76] and find that the small amount of sulphate in the lake waters is not incompatible with its direct derivation from the surrounding trap rocks which contain 0.023 per cent. of SO_4; the very low content of potassium in the lake water, as compared with the relative abundance of this element in the trap, is attributed to the fact that the insoluble products of rock decomposition, clays and soils, are capable of fixing considerable proprtions of potassium

[74] Rec. 32, 80-81 (1905).

[75] Rec. 70, 438 (1936).

[76] Rec. 41, 285 (1911)

and thus removing more of this element than sodium from percolating solutions.[77]

Sind and Khairpur.—Soda is obtained from a large number of alkaline lakes or *dhands* in eastern Sind and the State of Khairpur; from a remote past Sind is known to have yielded small quantities of this natural soda, which consists of urao (trona), $Na_2CO_3.NaHCO_3.2H_2O$, either in pure form or associated with chloride and sulphate. The local name for the product is *chaniho* or *kharo chaniho;* some of it is used locally but a large proportion is exported from Karachi, largely to Arabia.[78] In Sind and Khairpur it is employed principally in making light biscuits, but it is also used for washing clothes, hardening treacle, in soap-making and in the preparation of *goorakho* tobacco. The lakes are found in depressions among the sand-hills and occur exclusively in that portion of the country covered with wind-blown sand. They contain varying amounts of the carbonate, bicarbonate, chloride and sulphate of soda, with subordinate amounts of potash salts, and represent the accumulation of percolating water flowing in from the basal layer of the desert sand, below which the water is prevented from further sinking by the highly impervious alluvial clays which in the Sind desert everywhere underlie the wind-blown sand. This percolating water carries into the *dhands* the soluble salts of the buried soil. These salts are similar in composition to *reh;* within the limits of the alkaline areas, the carbonate and bicarbonate are as a rule preponderant, though some highly saline and one or two sulphate *dhands* occur. Cotter finds that, while the water of a *dhand* may be strongly alkaline or saline, it is customary to find the percolating water round its shores sweet and drinkable, with only a very small amount of dissolved salts.[79] The *dhands* of the Sind desert are really low-lying flat places where the original alluvial clay has remained more or less uncovered by sand. Although often large expanses of water, they are never very deep, and a *dhand* of one mile in length may be only ten feet deep in the middle; they are nothing more than huge, flat-bottomed evaporating pans in which the introduced salts are continually being concentrated. The shallower and smaller the *dhand,* the greater the concentration. The Sind *dhands* vary much with the season, being at their fullest after the monsoon rains and lowest in May or June, just before the break of the rains; the very small or very shallow *dhands* dry up completely. Cotter notes that the alkaline *dhand* can be distinguished even at a distance from the saline; around the margin of the former green grass is abundant and there are many trees, while the saline varieties are barren of grass and, except for a few halophytes such as tamarisk and salt-worts, are very bare of trees. Small tamarisk bushes are very common round the saline *dhands,* and in many cases have become completely encrusted with the gypsum which the saline *dhands* have deposited along with the chloride; these incrustations form curious knobby hillocks round the

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[77] See F. W. Clarke, Bull. U.S. Geol. Surv., 330, p. 107 (1908).
[78] Rec. 64, 434 (1930).
[79] Mem. 47, 209 (1923).

edge of the *dhand*. *Dhands* close to the Nara river are in many cases fresh, having had their salts washed out by floods and not since renewed; they can be recognised easily by the abundance of reeds and by the swarms of crocodile.

Reh in Burma.—The occurrence of *reh* on the surface of the soil in many parts of the dry zone in Burma has already been noticed; here it is chiefly characteristic of Pegu outcrops, is often found on Nummulitic rocks, but only sparingly on the Irrawadian and then nearly always in close proximity to outcrops of the Pegus. In Shwebo, the Lower Chindwin, Myitkyina and Sagaing districts it is known as "soap-sand" (*sapaya*) and used and sold locally for washing purposes.

The Punjab.[80]—The plains interected by the five great rivers which combine to form the lower Indus are not, as a rule, simply divided into *bhangar* and *khadar* like the plains of the United Provinces. In northeastern Rajputana the alluvium has all been assigned by Heron to the *bhangar,* forming what is believed to be the fringe of that formation.[81] It varies from a fine clay, corresponding to the loess of central Europe and the *pat* of Sind, to wind-blown sand; the latter or *bhur* land is usually the highest lying. In western Jaipur the soil, and the sub-soil beneath the loose sand is the usual light loam of the Indo-Gangetic plain.[82] In western Rajputana, the depression in which the salt of Pachbadra is collected is thought by La Touche to be a portion of an old bed of the Luni; further down, where the Luni makes a sudden bend southwards, there are distinct traces of this old river bed.[83] Nearly all the river courses of this region contain masses of sub-recent conglomerate, formed of well rolled pebbles and boulders of various crystalline rocks embedded in a calcareous sandy matrix. The conglomerate is always in horizontal layers, exposed in river sections, and sometimes filling cracks and fissures in the older rocks. As remarked by La Touche, these pebbles and boulders must have been transported at a time when the flow of water was much greater than it is now, for the present rivers, even in times of flood, are able to move little more than fine sand and gravel, and these deposits are seldom more rounded than subangular; nonetheless they belong to a period when the drainage of the country followed the same lines as does now. Good sections, 100-200 feet thick, of ordinary khaki-coloured alluvium with *kankar* and conglomerate are seen in the river cliffs below Ahmednagar; much of the alluvium of Idar, however, is probably more of the nature of wind-borne loess which can be seen banked up against hilly features as it can in western Rajputana.[84]

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[80] For fuller accounts the following papers may be consulted:—

Punjab—sketch of Geology, Punjab Gazetteer, Provincial volume, 1889, p. 22.

[81] Mem. 44, 100 (1917).

[82] Rec. 54, 383 (1922).

[83] Mem. 35, 14 (1902).

[84] Mem. 44, 143 (1921).

The Punjab rivers have a greater fall than the Ganges; their deposits are very sandy, and this character tends to diminish the pluvial denudation of the surface by allowing the water to sink into the soil. The action of winds upon the sand of the river, the formation of *bhur* land, and the elevation of the ground in the neighbourhood of the river banks above the intervening tracts as a result of the deposition of blown sand, are exhibited in the Punjab to a greater extent than in the Gangetic plain. To the southeast, the limits of the Punjab alluvium are difficult to trace, owing to the manner in which alluvium as well as rock is concealed by blown sand. The same is the case throughout the eastern margin of the Indus alluvial plain in Sind. The deposits of desert sand will be discussed at the end of this chapter.

The Lower Indus Plain.—The surface of the Indus alluvium in upper Sind differs but little from that in the Punjab; a considerable portion of the area is annually flooded and, as in Assam, the whole drainage of a great river being confined to a comparatively narrow tract, some permanent marshes of large size exist. The two most important marshy tracts are along the western edge of the valley from near Jacobabad to the Manchhar Lake near Sehwan, and along the eastern edge from Khairpur to below Umarkot. The latter is considered by some to represent the old channel of the Sutlej. In the neighbourhood of the Indus the ground is rather higher, having evidently been raised by the deposit of silt aided by the action of the wind on the sands of the river bed.

Along the edge of the Kirthar range, west of Sind, there is a well marked *bhabar* slope of gravel, but the breadth seldom exceeds two miles except where rivers debouch from the range. This gravel slope is absolutely barren and, like other features in Sind geology, is the more conspicuous for that reason.

The accumulation of fluviatile deposits in the Indus plain, and the consequent elevation of the surface is well seen in the vicinity of Umarkot, where the flood water from the Nara trickles through the sand-hills which form the limit of the Indus alluvium, and fills large hollows between the ridges of sand. The general surface of the Indus plain must, at no distant date, have been at least as low as the bottom of these hollows. During the floods, water leaves the Indus and flows southwards by the Eastern Nara, which must be regarded as a distributary, although its waters now seldom reach the sea. In the case of the Sutlej these flood waters are deflected as far up as Bahawalpur, long before this river joins the Indus, and are carried down to the Eastern Nara by way of the old Hakra or Ghaggar channel. The true head of the delta, however, is generally considered to be a little above Hyderabad, where the Phuleli (Fuleli) stream leaves the river.[85] The channels of the Indus delta change, perhaps more

[85] For description of the Indus delta see Lieut. T. G. Carless, Jour. Roy. Geogr. Soc. 8, 328 (1938), reprinted in Sel. Rec., Bombay Govt., 17, 461-500 (1855). Also J. F. Heddle, *ibid.*, p. 403. For ancient changes in the delta, see Cunningham, "Ancient Geography of India", p. 283, etc.

frequently than do those of the Ganges. The sea-face is, in all probability, determined by marine currents, and no great change is likely to take place through the deposition of sediment.

The eastern part of the Indus delta now receives but little water from the river. It is said that a large area of country in the neighbourhood of the Kori mouth was depressed during the earthquake of 1819, and that the great size of the Kori creek is due to the depression. The latter, which now drains into the Rann of Cutch, is continuous upstream with the Eastern Nara and this with the bed of the Hakra, Wandan or Wahind, the "Lost River" of the Indian desert, which formerly fed by the Sutlej and perhaps by other of the Punjab rivers and, in its lower course by the Indus, carried a powerful stream. A very large area northwest of the Kuri creek is covered with salt, sometimes a foot or even more in thickness, deposited from sea-water.

In the neighbourhood of the sea the soil is usually argillaceous and firm, but in the upper part of the delta the whole surface is composed of loose micaceous sand with but little clay, and the rivers in consequence find it easy to change their channels. The littoral portion of the delta lies so low that a broad tract of country is always overflown at spring tides, whilst the bottom of the sea in the vicinity of the coast is so shallow and the slope outwards so gradual that, in many places, large vessels cannot come within sight of land. A tract of country of variable width, but in places several miles across, lying along the sea face of the delta, is annually flooded by the rise of the river, the water being kept higher than it would otherwise be by the influence of the southwest monsoon.

The Thar or Great Indian Desert.—Though not, strictly speaking, part of the Indo-Gangetic alluvial plain, this will be a convenient place in which to describe that great accumulation of blown sand, situated in the tract between the Indus and the Aravalli hills and known as the Thar or Great Indian Desert. The dimensions of this tract are roughly about 400 miles long and 100 miles broad, but its limits are naturally vague and changeable. The name implies a greater degree of barrenness and solitude than is actually the case. Shrubs and grass tufts are scattered thinly over nearly the whole area and small trees are not infrequently met with; this region, in fact, supports large numbers of sheep and cattle, and a hardy people who have built cities and palaces and sunk deep wells. Though practically rainless in its upper parts, the desert at its Sind end receives quite an appreciable amount of rain, some of which is absorbed by the sand and sinks to the level of the impervious alluvial clay below. Cotter describes this portion of the desert as by no means so devoid of vegetation as Baluchistan, the only completely barren tracts being the constantly shifting plateaux of sand locally known as *dra-ins* and seen typically in Khairpur. Over the whole of the Thar desert sand-hills are scattered more or less thickly, but the greatest accumulation of blown sand forms a strip along the north of the Rann of Cutch, from which two arms extend, one northwards by Umarkot and thence sweeping round past Jaisalmer north-eastwards to Bikaner,

the other running north-eastwards between Barmer (Balmer) and Jodhpur and coalescing with the first around Bikaner; the enclosed tract of Jaisalmer, Barmer and Pokharan is rocky and contains comparatively few and scattered sand-hills. Jaipur State is, to a large extent, a vast expanse of light loam and sand-hills, the latter consisting of sand heaped up along the western faces of rock ridges and not resembling the travelling dunes of the more desert-like areas since they bear a scanty covering of tall *munj* grass and small shrubs.[86]

The sand-hills are of two types. One of them, the ordinary type of dune, has its longer axis at right angles to the prevailing direction of the wind; it presents a long gently sloping face to windward, up which the sand grains are driven, and a steep face to leeward, down which they roll and form a slope having the angle of repose of the dry sand. Belonging to this type are the "barchanes" or "burkhans" which have for many years threatened to overwhelm the suburb of Clifton near Karachi; these are crescent-shaped dunes with rounded cusps pointing to leeward and steep slopes along the inner concave side of the crescent. The other type is very largely developed in the Thar district of Sind, north of the Rann of Cutch, and is locally known as a *bhit*; it is a narrow ridge of sand, orientated N.E.-S.W. or N.N.E.-S.S.W., *i.e.*, parallel to the prevalent wind, with a steep slope on either side, the crest rising gradually in height to the northeastern extremity, which is usually the highest point of the ridge and beyond which is a steep slope downwards coinciding with the angle of repose of the sand. The valleys between the *bhits* are known as *talis* (*tullees*) and in them the orginally alluvial soil, which everywhere underlies the sand of the desert, is either at or very close to the surface; some of them contain the shallow salt lakes or *dhands* already described, while others which are superficially dry are studded with green shrubs and trees.[87] Both the *bhits* and *talis*, which cover most of this part of the desert have quite a vigorous flora of their own.

The mode of formation of the longitudinal type of sand-hill is not very easy to explain but, from the fact that where the two types are found together the longer axis of the one is at right angles to that of the other; it may be concluded that in both cases the form is decided by the direction and force of the wind, the longer axis being parallel in one case, and in the other transverse, to its prevailing direction. The steep slope of repose at the northeastern end of the longitudinal sand-hills indicates that they are formed of sand grains which have been driven along the surface of the ground by the wind, and not of grains light enough to be carried in suspension by the same agency, so that any theory of accumulation under the lee of bushes will not account for the facts and must be ruled out. If, however, one of the transverse type of sand-hills be examined, it will be noticed that the windward slope is by no means a uniform plane, but is composed of narrow ridges parallel to the direction of the wind, with intervening depressions, probably kept open by a concentration of the wind in

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[86] A. M. Heron, Rec. 43, 28 (1913).
[87] G. De. P. Cotter, Mem. 47, 207 (1923).

them and a consequent increase of transporting power. It seems probable that the longitudinal type of dune is due to an exaggeration of this effect, by which the depressions, instead of being comparatively shallow and separating mere saddles in the general ridge, are deepened almost, if not quite, to the base of the accumulation. However this may be, the restriction of the longitudinal type of dune to the seaward and western margins of the desert appears to show that they are connected with a greater wind force than the transverse type.

In western Rajputana the dunes in the open plain are all of the transverse type, except when formed under the lee of some rocky knoll where the sand forms a long ridge extending therefrom in a northeast direction. The sand here is also found banked up against the windward side of the hills, sometimes to a great height; at the western end of the Saora range the sand has banked to a height of over 800 feet above the plain. Usually the tops of such sand heaps do not actually reach the hill slopes but are separated from them by a deep ravine, kept clear by the drainage from the hill side, except where a projecting rocky spur throws off the drainage to either side.[88] Enormous masses of sand have been piled up against the westernmost ridge of the Shekhawati hills in western Jaipur,[89] where the same longitudinal ravine has been noted by Heron. The size of these sand-banks bears a direct proportion to the area of uninterrupted plain over which the wind has blown before encountering the rocky obstacle.[90] La Touche remarks on the curious aspect of a plain covered with sand ridges, such as that northwest of Pachbadra, when viewed from a height in the setting sun; the steep face of each dune casts an intensely black shadow, so that the country presents the appearance of a yellow plain crossed by a number of black parallel bars, the cause of which is not at the first glance evident. Towards the northeastern end of the desert, the sand-hills, though abundant, are low and contain a certain proportion of clay. This and a vegetation of specialised type including the tall *sirkanda* or *munj* grass, bind the sand and prevent its further advance; at the same time these dunes are protected from denudation by their porosity, for nearly all the rain falling upon them sinks in.[91] There is no typical dune formation in Idar but blown sand is a great hindrance to wheeled traffic on the roads.[92]

The height of the sand-hills of the Thar is considerable. They frequently exceed 100 feet and range in most places up to 200 feet; in the southern part of the desert, according to Sir Bartle Frere, they attain heights of 400 and 500 feet. It is scarcely credible that all the sand, though very similar in character, can have been derived directly from the Indus Valley, and the surface of the Rann of Cutch at present is too muddy to furnish any large supply. The sand grains are

[88] T. H. D. La Touche, Mem. 35, 37-38 (1902).
[89] Rec. 54, 384 (1922).
[90] Mem. 45, 102 (1917).
[91] A. M. Heron, Mem. 45, 102 (1917).
[92] Mem. 44, 143 (1921).

made up of quartz and shell fragments and smaller quantities of hornblende, mica and other rocks. On the shore near Karachi the sand was found by R. D. Oldham to contain 66·25 per cent. of shell fragments, and even in the dunes a little way inland this figure is over 50 and applies to all the coarser material.[93] In western Rajputana the composition was found by La Touche to be very uniform in widely separated localities, quartz grains predominating, while flakes of hornblende and felspar, as well as chips of the Malani lavas are common.[94] It is incorrect to speak of the sand grains as well rounded. Such a term is applicable more or less to the shell fragments and particles of carbonate of lime, but not apparently to the other ingredients. In the sand-hills near Karachi, while the grains of shell sand are almost all smooth and polished, those of the insoluble constituents consist of angular fragments of clear quartz, mixed with a small proportion of other minerals, principally a green hornblende and small flakes of mica. At the other end of the desert, in western Rajputana, where the percentage of carbonate of lime particles varies from less than 1 to as much as 10, the great majority of the other grains show little or no signs of attrition, and are in fact for the most part as sharp and angular as when they were broken off the parent rock. La Touche calls attention to the contrast between the effects of water and wind action which is well brought out in a sample from Teori, in which the ordinary dune sand is mingled with grains derived from the plateau of aqueously formed Vindhyan sandstone to the south; the latter, which are recognisable by their bright red colour, are all well rounded, "whereas the grains of dune sand are mostly quite angular". The survival of the particles of carbonate of lime and foraminifera among grains of hard material like quartz, after an aggregate journey of some 500 miles, shows that the amount of attrition that goes on must be very small. These calcareous particles and foraminifera—most of the latter flatly coiled tests belonging probably to the general *Rotalia* or *Pulvinulina*, are often coloured by iron oxide a bright yellow, a characteristic frequently seen in the Tertiary limestones of Cutch. The thick beds of calcareous tufa or *kankar* found universally among the desert sands of western Rajputana especially around the bases of isolated rocky knolls, is probably an aggregated massive form of this calcareous material derived from the coast of Cutch. The *kankar* of northeastern Rajputana, however, appears to be derived from local calcite-yielding rocks such as granite and limestone, and is found in large quantity.[95]

The grain of the sand in the open dunes is more uniform in size than it is on the lee side of rock outcrops. The larger and heavier grains tend to collect along the crests and in the furrows of the ripple-marks formed by the wind; where these coarser grains are composed of the bright red Vindhyan sandstone, as they are near Teori, northwest of Jodhpur, they form a vivid contrast to the yellowish buff colour of the ordinary sand, and a peculiar streaky appearance is given to the surface.

[93] Mem. 34, 150-151 (1903).
[94] Mem. 35, 38 (1902).
[95] Mem. 45, 103 (1917).

With regard to the derivation of the sand, we have seen that some of it has been blown up from the coast which, in all probability, lay a little further north than it does now. The most sandy tracts to-day are on the edge of the Indus valley, along the northern margin of the Rann, and along the depression of the Luni valley, and these portions of the country may have been situated at one time on the coast. At the same time, much of the desert sand appears to have been derived from local rocks which at no distant date must have been more widely exposed before they became so largely covered by the sand. The grains of Vindhyan sandstone in western Rajputana are examples of local origin. From the investigation of La Touche, local rocks might have furnished 90 per cent. and more of the sand in western Rajputana. It is significant that flakes of mica, which are very rare in the sand, appear to be almost confined to samples from the eastern margin of the desert where there are outcrops of micaceous schists and granites; in the interior of the desert, on the other hand, where the rocks do not contain mica, this ingredient is absent from the sand which, however, is characterised by abundant grains of the minerals found in the local Malani rhyolites and mica-less Siwana granite.

The collection of sand in the desert region is due in the first place to the low rainfall and to the consequent absence of streams; this effect is cumulative and is no doubt assisted by the salt-laden winds and saline surface conditions which prevent the growth of ordinary vegetation. In northeastern Rajputana Heron has found signs that erosion is at present in the ascendancy over accumulation and that the hills in the past have been much more deeply buried than they are to-day. Patches of sand are to be found high up on the hills, and the sand-hills to windward of the rock ridges are deeply dissected; everywhere in the neighbourhood of the hills, in fact, the streams seem to be deepening their beds and noticeably cutting back into the higher portions of the alluvium. The most obvious explanation of such a change is that the rainfall, small though it still is, is greater than it has been in the past.

Besides the occasional sand-hills of the Indus valley in Sind, there are some much larger tracts in the Punjab, repeating on a smaller scale the phenomena of the Thar desert. The most important of these is in the Sind-Sagar Doab between the Indus and the Jhelum, but there is a barren tract in the Rachna Doab between the Chenab and the Ravi, and sand-hills occur in places also in the Bari Doab between the Ravi and the Sutlej. In the sandy desert of western Baluchistan the sand dunes consist invariably of the barchanes or crescent-shaped variety of the transverse type. The sand in this region is slowly advancing over the plains, and entire ranges of low hills between Amir-Chah and Saindak have already been buried.[96]

[96] E. Vredenburg, Mem. 31, 215 (1907).

CHAPTER XXXVIII.

THE HIMALAYA AND THE RELATIONSHIP OF IT AND ITS CONTINUATIONS TO THE INDO-GANGETIC AND TO BRAHMAPUTRA PLAIN INCLUDING A BRIEF COMPARISON WITH BURMA.

The Himalaya and analogous ranges in other parts of the extra-Peninsular region: Definition and extent. Zonal subdivision. Main watershed. Meteorology. Vegetation. Fauna. Relationship to the Peninsular shield. Extreme scarcity of fossils. Gulfs in the Himalayan region. "The Great Boundary Fault". Tectonic features. Exotic blocks in the Tibetan zone. Metamorphism. Oblique orientations. Abnormally directed ridges. Age of the Himalaya. Uplift apart from plication. River capture. Lakes. Glaciation. Origin and history of the Indus, Brahmaputra and Ganges. Conditions of deposition in the trough. Earthquakes. Cause of the Himal yan uplift. Comparison with the tectonics of Burma.

THE HIMALAYA AND ANALOGOUS RANGES IN OTHER PARTS OF THE EXTRA-PENINSULAR REGION.

Definition and extent.—Some of the simpler physiographical aspects of the Himalaya have been already briefly described in the first chapter (p. 13). The Himalaya—the *Emodus* of Ptolemy—must not be regarded as merely the uptilted edge of the Tibetan plateau but as a lofty mountain range along the southern margin of this plateau, above which it soars many thousands of feet. Curved in a wide arc convex towards the S.S.W. it has a total length of about 1,350 miles measured along the chord of the arc, or of nearly 1,500 miles measured along the arc itself. Although having a general elevation above the sea varying from 14,000 to 16,000 feet, the southern portion of the Tibetan plateau is far from the region of permanent snow if we except the small glaciers draining the few local summits which attain 20,000 or 21,000 feet; glaciers in Tibet, in fact, do not descend to such low levels as do those which drain the southern slopes of the Himalaya. As a mountain range—or rather as a system of mountain ranges—the Himalaya may be regarded as embraced by the Indus at one end and the Brahmaputra at the other. Westwards, it terminates at a line joining the Indus gorge below Nanga Parbat to that portion of the Jhelum river which forms the western boundary of Punch State. Structurally and stratigraphically, the Himalayan ranges are continuous with the mountains of Chitral, Dir, Swat and the Hazara district[1] further west. The Karakoram is generally regarded as a range separate from and behind the Himalaya, though parallel to it and formed by the same folding movement. The pivotal points at the western end of the Himalaya and Karakoram are: the Pamirs, where the Karakoram bends round

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[1] Not the Hazara range of Afghanistan.

into the double-ranged Hindu Kush;[2] Nanga Parbat, a fit sentinel towering above the left bank of the Indus; and the vicinity of Muzaffarabad, where the bend of the hills and rock outcrops is extremely acute. At the eastern end, neither the geology nor the geography has been examined in the same detail, but the main range may be taken to terminate at the Tsangpo (Dihong or Dihang) as it sweeps round the isolated peak of Namcha Barwa and its satellite Sanglung, while the limit of that part of the Himalaya bordering the plains of India may be conveniently assumed to be the Dibong (Dibang) river. The Tsangpo and Dibong thus play the same roles at this end of the chain as the Indus and Jhelum respectively do at the other, while the place of Nanga Parbat is taken by Namcha Barwa. It must be confessed that these eastern limits, as defined above, are to some extent arbitrary, and no serious inconsistency would be involved by including another 175 miles of the mountains east of the Dihong and Dibong up to the point where they swing abruptly southwards towards Burma. Reasoning not only by analogy with conditions at the western end but also from some limited field evidence, there is here the same structural and stratigraphical continuity with the Patkoi-Arakan ranges, the Shan plateau and the ranges of Indo-China. The ranges of the North-West Frontier, Afghanistan and Baluchistan, on the one side, and those of Burma, Malaysia and Indo China on the other, belong to the same great series of earth movements as that which produced the Himalaya.

Zonal subdivision.—We have spoken of the Himalaya as divided into four chief zones: the Tibetan geosynclinal zone of sedimentaries, the Great Himalaya or line of maximum peaks, the Lesser Himalaya to the south of it, and the Sub-Himalaya or Upper Tertiary and Pleistocene zone bordering the alluvial plain. The physiography, however, as well as the structure and stratigraphy, is by no means always so constant and cleanly defined. This becomes at once apparent when an attempt is made to trace the continuity of any particular range. Nor do the structural units always coincide with the topographical. In the north-western portion of the Himalaya, where alone the geography is known with any degree of completeness, five or six principal ranges are commonly recognised. To the north of these is the lofty Karakoram or Mustagh, whose culminating peak, 28,250 feet high and perhaps the second highest in the world,[3] was formerly known as K-2 but is now often named after its discoverer, Godwin-Austen. Although possessing a less number of high peaks than the Great Himalaya, the Karakoram has a greater length of high range; while in the Great Himalaya the aggregate length of crest carrying summits over 24,000 feet is about 7 per cent. of the total length of crest, the corresponding figure in the case of the Karakoram is more than 26 per cent. Other peaks in the Karakoram besides that of Godwin-Austen are the four summits of Gasherbrum (I-26, 470 feet;

[2] The average altitude of the Pamir alluvial plateau behind the Karakoram-Hindu Kush syntaxis is 12,000 ft.

[3] 28,191 feet may be a more correct estimate, making it the third highest peak known.

II-26,360 feet; III-26,090 feet; and IV-26,000 feet) and the two heights of Masherbrum (East-25,660 feet, and West-25,610 feet). Associated with the Karakoram to the south is a limited and ill-defined belt of mountains spoken of as the Kailas range; its highest peak is Rakaposhi (25,550 feet), terminating the range to the northwest, where the Hunza river breaks its way southwards through the mountains. South of and more or less parallel to the Kailas comes the Ladakh, a range which may be regarded as commencing near the junction of the Indus with its tributary the Shayok (Shyok) and stretching thence south-eastwards along the north side of the Indus valley. This range, which has a marked individuality both geographically and geologically, is breached by the Indus at about 150 miles from its northwesterly end; the range continues south-eastwards as far as Hanle, there forming the south instead of the north side of the Indus valley, and its further continuation as far as the Sutlej and across that river up to the Manasarowar lakes is comparatively well defined. The Zanskar range merges at both ends into what is known as the Great Himalaya, and appears to owe its existence to the accident that it forms the watershed between the Indus and the Chenab drainage. Northwest of the Chenab, the outermost of the principal ranges is the Pir Panjal, south of the valley of Kashmir; on the other side of the Chenab, the place of the Pir Panjal is taken by the Dhauladhar, flanked on the plains side by the sub-Himalayan foot-hills which here begin to acquire their name of Siwalik. Towards the eastern portion of the Himalaya, in the neighbourhood of Darjeeling, there are well marked ranges running transversely across the chain; it is here that the Himalaya is narrowest, the width in the Everest area being no more than 80 miles measured from the edge of the Tibetan plateau to the plains of India. The last Himalayan peak in this direction, Namcha Barwa, is 25,445 feet in height, towering nearly 18,000 feet above the Tsangpo on its southern bank.

The physiographical individuality of Himalayan ranges is a subject which has provoked more discussion than it deserves. From a geological aspect, at any rate, it is of minor importance and largely an accidental result of the relative resistance to denudation of the rocks, a character which is not even dependent to any large extent on their age. In spite of this, it is possible and convenient, throughout a large section of the chain, to divide the mountains into physiographical regions sufficiently distinct from each other, even if their exact boundaries are somewhat indefinite. It is at the two ends of the chain that this subdivision breaks down most; at the western end there is a multiplicity of individual ranges, as we have seen, while in the east, in Sikkim, and Darjeeling there is no geographical distinction between the Great range, the Lesser Himalaya and the Sub-Himalaya, the ground rising more or less uniformly from the plains to the line of maximum elevation.

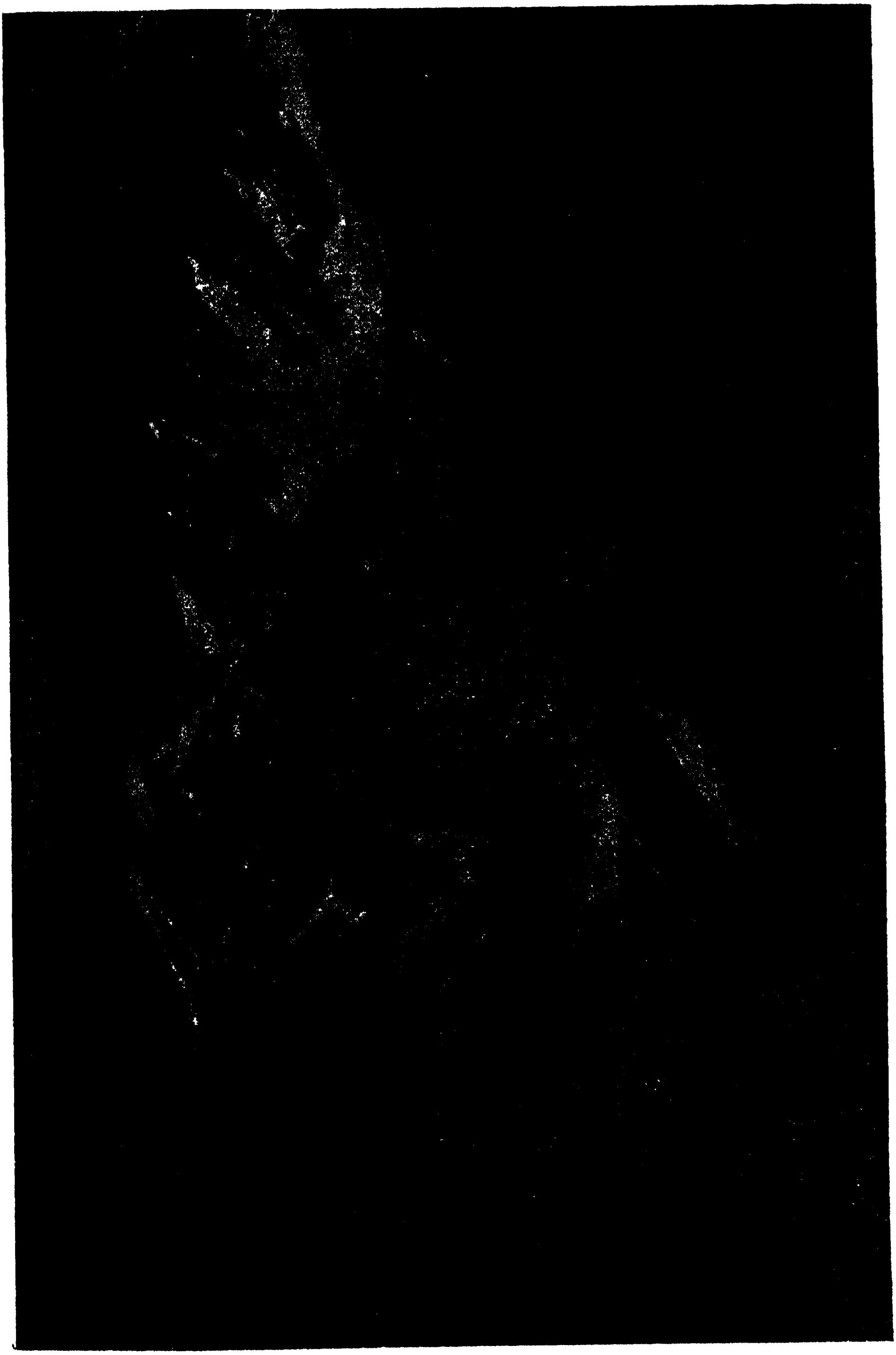
The innermost or Tibetan zone, some 25 miles across, is deeply trenched by southwardly flowing rivers so that, according to Burrard and Hayden, while the average height of the river troughs is 14,000 feet, that of the intervening mountains is 19,000 feet. This zone is

not without metamorphism, nor without thrust-faulting, in some places on a considerable scale. Besides a great elevation, it has a dry climate, for very little moisture reaches the north side of the Great Himalayan range; the result is a very extensive accumulation of detritus in the valleys of the plateau north of the zone. This Tibetan Plateau—or "Chang", as it is called in the vernacular—breaks up eastwards about the meridian of 92° E., giving place to a wild region of mountains which become systematised into concentric ranges round the valley of Upper Assam. The drainage of the southern fringe of Tibet, except that of the comparatively small area drained by the upper Sutlej river, escapes into the Brahmaputra and Indus valleys at the extremities of the Himalayan chain, but by far the greater portion of central Tibet forms part of a closed system and most of the drainage which does escape from this area finds its way into rivers outside India. Built up of more than 20,000 feet of sediments, almost entirely marine in character, the Tibetan zone along its southern border is in contact with a granite which is described as throwing out branches into and metamorphosing the component members of the sedimentaries. This is the Tertiary granite which is believed to form so much of the core of the Himalayan axis. At the eastern end of the chain, it is found in great intrusive masses in the younger Mesozoic rocks, and forms conspicuous outcrops in the valleys of the Tsangpo and Kyi Chu as well as in the immediate neighbourhood of Lhasa.[4] This intrusion in many places takes the form of a tourmaline-muscovite pegmatite which has injected itself among the banded biotite genisses, sometimes to such an extent as to form the predominant rock.[5] Except in its western portion, the topography of the Tibetan zone is much more subdued than that of the main range to the south and consists largely of lumpy hills of sedimentary rocks and wide, open, flat-bottomed valleys choked with detritus. At the Kashmir end, where the main drainage is to the northwest or west, the Tibetan zone is interrupted by the Karakoram range which is comparable in most of its physiographical and structural features with the Great Himalaya. The Tibetan zone is an intensely folded one, the predominant dip of the axial planes being towards the north. Most of the rock systems from Cambrian to Eocene are represented in this broad belt of marine fossiliferous sediments from Hazara and Kashmir through Spiti, Garhwal and Kumaon to Nepal and beyond.

South of the Tibetan region rises the higher, steeper and more rugged zone of snowy peaks, 15 miles broad and with an average height above sea-level exceeding 20,000 feet; few of its passes are under 16,000 feet in elevation. The drainage of this zone, from both northern and southern slopes finds its way southwards, in a more or less directly transverse direction, on to the Indo-Gangetic plain. Rising steeply like a wall from the Lesser Himalaya, the whole of this zone, with the exception of the deeper river ravines,

[4] Rec. 32, pt. 2, 155 (1905).

[5] Burrard and Hayden, "A sketch of the Geography and Geology of the Himalaya Mountains and Tibet", p. 219 (1907).



lies above the limits of perpetual snow. This constantly renewed covering of snow must have done much in counteracting the forces of denudation and in preventing their neutralising effect upon the continued upheaval. While the upper snow-capped portions of the Great Range were thus afforded some protection, its southern flank has been exposed to all the rigours of rain-scouring and the alternate freezing and melting of water precipitated from the monsoon clouds. In this way has the steep wall-like southern face of the Great Himalaya been carved out, steep scarp slopes facing the plains and gentler dip slopes facing northwards towards Tibet in a manner so well exemplified in Garhwal.[6] Earth movement has not yet ceased in the Himalaya and it is an interesting question whether parts of it may not be attaining higher altitudes, the permanent protective covering of snow preventing the disintegration of the crestal portions where these are level enough to retain the snow.

The line of maximum peaks is situated at an average distance of about 90 miles from the southern limit of the chain, but this distance varies from a maximum of 115 to a minimum of 60 miles. The actual watershed of the transverse drainage across this zone has an average elevation of no more than 18,000 feet, and lies some 30 or 40 miles northeast of the line of maximum peaks, which is repeatedly interrupted by the deep valleys of the rivers traversing it. Nepal contains not only the highest peaks of all, but the greatest number of high peaks; next in general elevation comes Kumaon, then with a big drop Assam, and finally the Punjab section which is not far short of Assam. In several sections, this zone is made up of three elements: (i) intrusive granite, (ii) complex schists resulting from the intrusion of granite into rocks which it has partially absorbed, and (iii) old gneisses, schists, granulites and highly metamorphosed crystalline limestones, which may include both pre-Cambrian and Palaeozoic representatives. In the Everest area the main range includes sedimentary beds assigned to the Jurassic or Trias and others referred to the Carboniferous.

South of the snowy peaks stretches a zone of lower hills, seldom rising much over 12,000 feet above the sea and distinguished as the Lesser Himalaya. Averaging about 50 miles in width, it is composed largely of unfossiliferous sediments believed to include Purana, Palaeozoic and Mesozoic representatives. As already observed in the first chapter, the Lesser Himalaya consists chiefly of four branches issuing obliquely from points in the Great Range, and of three outer disconnected ranges. The oblique branches are given off westwards, decreasing in height from their proximal ends. They comprise: (i) Nag Tibba, given off from Dhaulagiri, (ii) the Dhauladhar from the neighbourhood of Badrinath, (iii) the Pir Panjal, the largest of the Lesser ranges, from the Sutlej gorge, and (iv) the North Kashmir range from the Zoji La, separating the Jhelum and Kishenganga rivers. The three outer parallel ranges, which form a well marked feature dividing the high central range from the low ranges

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[6] Rec. 71, pt. 4, 409 (1936).

of the Sub-Himalaya, are : (a) the Mahabarat, stretching from the meridian of Kinchinjunga through western Nepal, (b) the so-called Mussoorie range between the Ganges and Sutlej, and (c) Rattan Pir, in south-western Kashmir, separated from the Pir Panjal by the river Punch. The Dhauladhar and part of the Pir Panjal rise more or less directly from the Sub-Himalayan zone. In Kumaon, the summits of the Lesser Himalaya are not arranged in the distinct alignments seen in the Punjab and Nepal but, though scattered irregularly, they exhibit a uniformity of height varying between 6,000 and 10,000 feet. While the alignment of these ranges in Nepal is mainly parallel to that of the Great Range, the Lesser ranges in the Punjab are for the most part oblique to the main range.

The Sub-Himalaya or outermost zone is usually marked by an abrupt drop in the average height of the hills. From 5 to 30 miles in width and occasionally missing altogether, this zone seldom rises above 4,000 feet, and is exclusively composed of Tertiary and Pleistocene deposits, the Tertiary belonging almost entirely to the upper division of that system. Throughout a large proportion of the Himalaya, the Siwalik ranges are separated from the Lesser Himalaya, for distances varying from 20 to 50 miles, by longitudinal flat-bottomed valleys called *duns,* which are usually spindle-shaped and filled with a gravelly alluvium. The best known of these is Dehra Dun, stretching from the Ganges to the Jumna, others being the Kotah, Patli, Kothri, Chgumbi, Kyarda, and many in Nepal. The Sub-Himalayan zone has been traced from the deep and narrow gorge of the Jhelum, through the Simla foot-hills, the ridges and *duns* of the Siwalik range below Mussorie, the *sal*-covered spurs above Kathgodam, and the dense jungle of the Darjeeling *tarai,* to the head of the Assam valley. In the eastern Himalaya, however, it has no physiographical individuality but occupies the basal slopes of the chain ; at the other end of the chain also the physiography shows irregularity and does not conform entirely to geological distinctions. The sudden drop in average height typically seen between the Lesser Himalayan and Sub-Himalayan zones is due partly to the greater softness of the rocks composing the latter, and partly to the smaller amount of elevatory movement to which the younger rocks have been subjected. The superior height of the Great Himalaya over the Lesser is probably due chiefly to similar tectonic causes, though here and there it is possible that the greater resistance to erosion of the rocks of the main range has played an appreciable part in their present superior elevation.

Main watershed.—Throughout a length of 360 miles, from the Sutlej to the Indus, no river crosses the Great Himalaya of the Punjab. In other portions of the chain, however, rivers intersect the Great Range every 50 or 60 miles in profound gorges which are among the wonders of this part of India. Owing to the convergence of streams, there are more gorges in the Great than in the Lesser Range. The Alaknanda and Bhagirathi for instance, have both cut passages for themselves through the Great Range, but unite before they pierce the Lesser Himalaya and the Siwalik hills into one joint stream, the

Ganges. Three affluents of the Kali pass the Great Himalayan range through independent gorges but unite within the lower hills before reaching the plains. Similar convergence can be noted in the cases of the Gandak, the Kosi and the Manas.[7] Sometimes, as in the case of the Alaknanda, the formation of the gorge has been facilitated by a fault.

Two hypotheses have been put forward to explain the fact that the watershed between the northerly and the southerly drainage of the Himalaya lies, not along the line of maximum summits, but at a considerable distance to the north thereof, along what is generally referred to as the Ladakh range.[8] One view attributes this peculiarity to the far greater rainfall experienced by the southern slopes as compared with the northern. The southwest monsoon, still heavily laden with moisture in spite of its transit over the Indian peninsula, deposits nearly all its remaining burden on the southerly slopes of the Himalaya, and very little of the moisture succeeds in getting over the crest of the range. The extremely small amount which does find its way to the Tibetan plateau does so in all probability by drifting through the deeper gorges. The transverse streams flowing north, therefore, have no chance against those flowing south, which, it is suggested, have cut back through the Great Himalayan range into the Tibetan zone beyond, where they now take their rise. The Lachen river to the east of Kinchinjunga, for instance, is thought to have captured much of what was formerly the watershed between the northern and southern systems of drainage; this deduction follows from the presence of erratic blocks of granite derived from the Kinchinjunga *massif* stranded on the hills above the surrounding Yaru plain, proving that the drainage from Kinchinjunga and its neighbourhood must at one time have had a northerly trend. Even the Yaru valley plain itself, now draining into Nepal, may have been captured from the northern system by the gradual encroachment of the southwardly flowing streams. Another example of this northward retreat of the drainage is recorded by General Strachy[9] who found that the sub-Recent deposits of the Sutlej valley in Hundes extend southwards right up to the crest of the Niti Pass, and that a detached portion of them is even to be seen two or three miles south of the crest; it is evident that the original watershed bounding the Sutlej must have run further south than it does now, and the occurrence of an outlier of the old river silt in what is now the southern drainage area, if correctly so identified, is proof of a still further encroachment on the northern drainage area.

That some such unequal contest is taking place between the southern and northern drainage seems indicated in the profiles of the valleys on each side of the watershed. From the admirable maps

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[7] Burrard and Hayden, "A sketch of the Geography and Geology of the Himalaya Mountains and Tibet", 190 (1907).

[8] This peculiarity is in places so striking that it is responsible for a claim made in the past that the high peaks don't form part of a range but stand on spurs from the Tibetan Zone.

[9] Journ. Roy. Geogr. Soc. 21, 63 (1851).

of the Survey of India, especially those of north Kumaon and Garhwal, as well as from the accounts of travellers, the slopes on the southern side of the passes are much steeper than on the northern ; the more rapid erosion of the southerly slopes might thus force the watershed gradually northward.

According to the alternative hypothesis, the transverse components of the Himalayan rivers are of antecedent character and occupy channels which were in existence before the formation of the hill ranges they traverse. Without rejecting the probability that in some cases, such as that of the Sutlej, there has been cutting back, even through the main range, and recent capture of streams on the northern side, we find grounds for concluding that many at least of the stream gorges which traverse the Great Himalaya are antecedent and that their channels existed before the uprise of this central part of the mountain belt. In other words, the gorges have deepened *pari passu* with the slow upheaval of the hills, and in this way have kept open their valleys by cutting them down at a pace sufficient to prevent reversal of drainage as a result of the upheaval.

The general fact that the axis range is far more frequently pierced by streams in the east, where the rainfall is heavy, than it is in the west, where the rainfall is comparatively light, might seem to support the theory that the piercing of the main range is the direct result of the cutting back of the streams across an already existing range; the Punjab Himalaya, between the Indus and Sutlej gorges, is unpierced by any considerable stream. On the other hand, this present contrast between east and west is not conclusively antagonistic to the idea of antecedent drainage ; it might mean merely that streams in west, traversing the beginnings of the Great Himalaya as they may have done, were prevented by insufficient rainfall from maintaining these traverses, and unable to compete with the too rapid rise of the main mountain axis across their courses.

In considering the relative merits of the two hypotheses, certain general conclusions, in the first place, can be drawn from the nature of the Siwalik deposits. Omitting the final stage of the Boulder Conglomerate, the Siwalik sediments exhibit a general fineness of character which has been commented upon by more than one observer, and may be accepted as an indication of good grading along the river profiles during all but the latest of the Siwalik epochs. Coarse deposits are conspicuously uncommon except towards the top of this enormous thickness of river silts, and by that time the Himalaya must have attained an elevation not far from, if at all, short of what it has today ; from that time onwards, also, the principal Himalyan rivers have maintained their ancient courses within the belt of hills, as is shown by the constant disposition of the modern gravels as well as the Boulder Conglomerate around the debouchures of these rivers on to the plains.

More specific evidence of antecedent drainage has recently been adduced by L. R. Wager in the case of the Arun, one of the rivers

which, curiously enough, has been quoted as an example of cutting back and capture. This river has its origin in a series of feeders from the so-called Ladakh range,[10] a comparatively low watershed south of the Tsangpo and nowhere rising above 22,000 feet in elevation. After its course from west to east it turns abruptly south and cuts its way in a series of gorges right through the Great Himalaya which, as Wager points out, is here at its highest, with Everest immediately to the west and Kinchinjunga immediately to the east, both of them 7,000 feet above the highest peaks of the Ladakh range where the river has its source.[11]

This idea is further developed by Wager who points out that, were the mountains of the Everest country piled into the adjacent valleys, in order to restore what may conceivably have been the original geodetic contour of the surface, the line of the main range would have an elevation of about 15,500 feet, *i.e.*, a little lower than that of the Tibetan plateau further north, which is here about 16,000 feet. It is then suggested that, if the Arun and Tista originated on such a surface, they must have flowed southwards from Tibet from the beginning. That the trans-Himalayan portion of the Arun (usually known as the Phung Chu) occupies a channel of some antiquity is confirmed by its behaviour along the upper of its two main gorges; here, at Yori, thirty or forty miles northeast of the Everest summit, the river is seen to cut along two sides of a triangle in hard gneiss instead of following the hypotenuse along relatively soft schists over the Kuyok La.[12] Wager rightly remarks that, had the Arun ever flowed over the Kuyok La in the relatively soft rock, it would never have shifted by any normal process of river capture to its present course through the corner of a mountain mass of much greater height and composed of harder rocks.[13] The only satisfactory explanation of the anomalous behaviour of the Arun at Yori seems to lie in the presumption that the Yori channel was in existence before the rise of the encircling hills, and formed part of a river which, from the beginning, traversed the main Himalayan range. Heron has suggested that the upper portion of the Arun or Phung Chu originally continued eastwards through the Jikkyop gap and over the plain to Kampa Dzong, and that it was captured by the lower Arun in the neighbourhood of the gap; if the antecedent nature of the Arun gorges be a correct deduction, this capture is likely to have been effected in the earlier half of the Tertiary period, before the Great Himalaya rose to its present pre-eminence.

The Tista is another river whose channel shows similar definite indications of having existed prior to the rise of that particular part of the range.

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[10] Presumably so named because it is the most northerly of the Himalayan ranges and, like its namesake in Kashmir, situated to the north of the main range.

[11] Ruttledge, "Everest 1933", 328 (1934).

[12] Heron, Rec. 54, pt. 2, 219 (1922).

[13] Geogr. Journ. 89, No. 3, 239 (1937).

There are grounds for believing that the geosyncline or hydrographic line of the Tsangpo was a very early feature in Himalayan history and was separated from the similar hydrographic line which afterwards became the Indo-Gangetic trough by a watershed range. Giving due weight to all the facts, it seems justifiable to conclude: (i) that the edge of the Tibetan plateau rose to form a watershed which coincides closely with the modern Ladakh or "Northern" range and has existed since early Tertiary times, separating the Tibetan from the Indian drainage, as it does today; (ii) that the main range of the Himalaya rose subsequently parallel to and to the south of this watershed range, the southerly streams from the latter deepening and preserving their channels across the Great Range as it slowly rose and eventually overtopped the Ladakh or watershed range; (iii) that the streams across the Punjab end of the chain failed to preserve their channels across the Great Himalaya by reason of deficient moisture; (iv) that ever since the establishment of a monsoon climate, which may have been effected quite early in the Tertiary period, the southerly drainage of the Himalaya has become increasingly more powerful than the northerly, and in a few cases may have cut back through the main range; and (v) that the gorges so produced are not likely to be as profound as the gorges of the antecedent streams, except in cases like the Sutlej where a large longitudinal river has been captured on the north side of the main range by the invading stream.

In only one case does a stream of any considerable size traverse the Ladkah or principal watershed range; this is the Nyang, a tributary of the Tsangpo which has cut its way back through the range to the north of Chumalhari peak, and rises in two lakes on the slopes of the Great Himalaya.

Meteorology.—The temperature rapidly decreases with altitude in the Himalaya, approximate average being a fall of 1° for every 300 feet rise; this decrease is more rapid in summer than in winter. Locally the temperature is largely modified by the distribution of vegetation and by physiographical detail. "For instance, it may be found that the difference of temperature between forest-clad ranges and the Indian plains is twice as much in April and May as in December or January; and the difference between the temperature of a well-wooded hill-top and the open valley below may vary from 9° to 24° within the twenty-four hours".[14] In the words of Sir Thomas Holditch, "one half of the total mass of the atmosphere and three-fourths of the water suspended in it in the form of vapour lie below the average altitude of the Himalaya; and of the residue, one half of the air and virtually almost all the vapour come within the influence of the highest peaks." "The amount of vapour held in suspension diminishes so rapidly with the altitude that not more than one-sixth (sometimes only one-tenth) of that observed at the foot of the mountains is found at the greatest heights."

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[14] Col. Sir Thomas Holditch, Encyclopaedia Britannica: "Himalaya" (13th edition).

The principal rainfall occurs during the monsoon period between the end of May and October, the rest of the year being comparatively dry. The largest falls take place in the outer ranges, the quantity diminishing as we pass across the chain till, behind the line of snowy peaks, the rainfall is so small as to be scarcely perceptible of measurement.

Across the mountain barrier, there appears to be a constant flow of air, especially during the daytime, to the arid tableland of Tibet. Where the Himalayan rivers debouch on to the plains of India, however, there is a nocturnal current of cooled air from the southern slopes, producing a wind of some strength, especially in the early morning hours. Condensation of vapour from diurnal ascending currents of wind and their gradual exhaustion as they are precipitated on successive ranges is, in the words of Holditch, "very obvious in the cloud effects produced during the monsoon, the southern or windward face of each range being clothed day after day with a white crest of cloud, whilst the northern slopes are often left entirely free".

Vegetation.—Plant genera common to Europe and the Himalaya are abundant throughout the latter region and occur at all elevations. Many European species are to be found as far as the Central parts of the chain, though few of them reach to the eastern end. The columbine and hawthorn, for example, common in the west, disappear rapidly eastwards and are scarce beyond Kumaon; the Holm Oak (*Quercus ilex*) of the western Himalaya is a characteristic Mediterranean species. Species identical with those of Europe become more frequent at the greater elevations. In contrast to the European element in the Himalayan flora, an influx of Chinese and Japanese forms has also taken place, and is evident in the presence of the tea plant, *Rhododendron, Magnolia, Aucuba, Helwingia, Abelia, Skimmia, Adamia, Goughia* and others; these are more numerous in the east, most of them disappearing westwards. The dominant tree of the Himalayan foot-hills is the *chil* or *chir* (*Pinus longifolia*). The northern limit of this Tertiary zone coincides approximately with that of the *sal* (*Shorea robusta*), one of the most valuable of the timber trees. Oak and rhododendron are characteristic of higher elevations. The rhododendron begins at about 6,000 feet and becomes abundant at 8,000 feet; between 10,000 and 14,000 feet in many places it forms a mass of shrubby vegetation extending in the form of a belt some 2,000 feet above the forest. Of the east-to-west ranges and ridges the northern slopes are often thickly clothed with a dense forest of deodar, oak and pine, while the southern are almost bare of vegetation; this is due to the fact that the northern slopes retain snow and moisture for a longer period than do the steeper scarps of the southern slopes, and in this way afford the vegetation more persistently favourable conditions for growth. An excellent example of this contrast is seen in the well known Shali ridge northeast of Simla. Epiphytal orchids are extremely numerous between the 6,000-foot and 8,000-foot contours.

Funa.—To the Himalayan fauna only the briefest reference is possible, although from the Tibetan border to the Indo-Gangetic plain

the Himalayan ranges form one of the richest zoological regions in the world. A connection with Europe, China, Africa and Malaya is clearly indicated. Large and gorgeous butterflies in favoured localities are second in number, beauty and variety only to those of South America. Strange moths of great size are common. The noisy cicada is a typical autumn feature of the woods, and locusts frequently appear in swarms after the summer. Many of the genera and species of fish are organised for a mountain-torrent life and are furnished with suckers to enable them to hang on to rocks and stones in the rapid streams they inhabit. Of the reptiles many are peculiar. The python and cobra are present, while lizards and frogs are plentiful. The marvellous variety of birds, for whom the forest-clad mountains of the eastern Himalaya afford an asylum having almost every range of temperature, is rivalled only in Central and South America. The mammals are too numerous to mention *in extenso*, but include: two or three forms of monkey, many bats, moles unknown in the Peninsula, some remarkable water shrews, many bears, leopards, tigers, smaller cats, weasels, otters, the remarkable cat-bear (*Aelurus*) akin to the American recoon, wild dogs, a badger and civet cat both aberrant and both Malayan in type, squirrels, rats (including the bamboo rat *Rhizomys*), mice, voles, porcupines, elephant, rhinoceros, wild pig, including a very small pigmy hog, deer, wild oxen (gaur), three very characteristic ruminants—the *sarao* (*Nemorhaedus bubalinus*), the *gural* (*Cemas*) and the *tahr* (*Hemitragus*)—and two species of pangolin. The dolphin, *Platanista*, is referred to in later pages.

Middlemiss calls attention to the fact that the Sub-Himalayan hills constitute a sort of meeting-ground for the fauna of the hills and that of the plains, and are especially rich in wild animals. The Indian elephant is at home in the seclusion of the forests thereof ; here also the wild dog hunts in packs, slaying large numbers of deer. The commonest deer in this lower country is the *chital* or spotted deer (*Cervus axis*), which buries itself in the thick *sal* forests during the heat of the day, while the small hog-deer (*Cervus porcinus*) frequents the marshy parts of the longitudinal stream-beds. The *sarao* and *gural* are often seen in these lower tracts, where also the wild boar is not uncommon.

The fauna of the Tibetan Himalaya is essentially European. Characteristic animals of these parts are: the yak, many wild sheep, two antelopes, the muskdeer, certain arctic forms of carnivora and wild asses. The lizards belong for the most part to types characteristic of Central Asia. The bulk of the fishes from the upper Indus are also Central Asiatic types with a small admixture of purely Himalayan forms ; among the former are several peculiar small-scaled carps belonging or allied to the genus, *Schizothorax*.

Relationship to the Peninsular shield.—The contrast between the richly fossiliferous sediments of the Tibetan zone and the almost completely barren beds on the south side of the main Himalayan axis is so constant and widespread that the equivalence of these formations in these two regions, at any rate in conditions of deposition, is

incredible. The Lesser ranges, and in some parts the main range, include, as we have seen, representatives of Peninsular rocks, and it is now well established that the northern margin of the old Gondwana continent was involved in the mountain building. It is, in fact, possible that the Lesser Himalaya belongs largely to the Purana and Vindhyan systems of the Peninsula. Some of the resemblances to Peninsular rocks, however, may be counterfeit. The crystalline belt of the Himalaya, for instance, includes ancient gneisses, schists, granulites and crystalline limestones, which are said to show a marked similarity to Peninsular types in Madras, Burma, Ceylon, the Central Provinces and Rajputana, referred to the Archaean ; it is, however, by no means impossible that the metamorphism exhibited by these Himalayan rocks was brought about by the intrusion of subsequent granite and has no stratigraphical significance. The only rocks identified as probably pre-Cambrian by their stratigraphical position are the Salkhalas of Kashmir, of which the Jutoghs in the Simla region may be the equivalent. There can be no mistake, on the other hand, in the case of certain members of the Gondwana system. The coal-bearing Damuda series is easily recognisable in the Darjeeling and Assam foot-hills and in eastern Nepal. These are subaerially formed deposits and the inference that they were produced on the same land tract as those of the Peninsula and were separated therefrom by no depression corresponding to the Indo-Gangetic alluvium at the time of their deposition is highly probable. Some of these coal occurrences are underlain by a glacial tillite identical with the Talchir Boulder Bed of the Peninsular region, while near Tindharia and along the Tista valley, Fox has found in the coal, intrusions of the same lamprophyre and mica-peridotite which have spoilt so much coal in the Bokaro, Jharia and Raniganj coalfields of the Damodar valley.[15] In Sikkim examples of what are thought to be the equivalents of the Talchir glacial deposits have been found on the north side of the Great Range. The Talchir formation may be represented also by the Blaini and Mandhali beds of Garhwal and the Simla area. In Kashmir the Gondwana rocks spread far to the north. The Talchir Boulder Bed and other portions of the Damuda sequence are found in the Salt Range, which is structurally an outlying part of the Himalaya. The boulder bed has been recognised near Abbottabad in the Hazara district. The Gondwanas are not seen in the Mishmi hills which are a continuation of the Himalaya on the other side of the Dibong. Rocks underlying the Chandragiri (Ordovician) limestones in Nepal are described by Auden as showing a striking resemblance to the Semri division of the Vindhyan system.[16] The mottled green and purple Nagthat sandstones of Garhwal can also be matched with members of the Vindhyan succession.[17] Conversely too, some of the types seen more especially in Extra-Peninsular regions, occur in isolated outcrops on the Peninsular side of the Indo-Gangetic alluvium. The marine Permian found in the Salt

[15] Mem. 59, 50 (1934).
[16] Rec. 69, pt. 2, 140 (1935).
[17] Rec. 72, pt. 1, 84 (1937).

Range and Kashmir and suspected to occur also in the Subansiri gorge and the Abor Hills of the eastern Himalaya has been found cropping out in the Rewah State.

The presence of transverse strikes and structures in one section of the Himalaya, attributed to relics of the Aravalli folding and further mentioned in the sequel, also suggest a northward extension of Peninsular rocks into the Himalayan region; these original structures, although involved in the Tertiary movement, appear to have escaped rotation thereby.

The Himalaya in reality consists of two portions, one of which belongs to Peninsular India and is represented at the present time by most of the Lesser Himalaya and at one time perhaps by the whole of Sikkim,[18] the other belonging to the Tethys geosynclinal and occupying the north flank of the chain. Round the western end of Kashmir, the Tethys portion has invaded for some distance the area occupied by the Peninsular, and at the other end of the chain Tethys sediments are found in the main range of the Mount Everest region.

Extreme scarcity of fossils.—Several attempts have been made to explain the remarkable absence of fossils in practically all the pre-Tertiary rocks on the Indian side of the main range. Many of the limestones, such as those of the Simla area, may have lost all trace of organic structure through the dolomitisation which they have undergone. Some of the beds appear to have accumulated under desert conditions, but it is difficult to accept the suggestion that physical conditions in this southern sea, if the area concerned persisted as a sea, remained inimical to life over so long a period as the unfossiliferous sequence must represent. The shallow-water nature of some of the deposits might account for their barrenness, but there are others for which this plea could not be made, and it must be confessed that no satisfactory explanation of the apparently lifeless character of beds like the Simla Slates, many of the Jaunsar rocks, Infra-Krols, and Tals, has yet been advanced.

Gulfs in the Himalayan region.—In this connection, mention must be made of a few fossils found along the southern flank of the Himalaya by C. S. Middlemiss and apparently of pre-Tertiary age; these include belemnites and were obtained in the Pillani valley, south of Lansdowne. They may be Jurassic or Cretaceous, and the occurrence of fossiliferous Mesozoic rocks so far along the range from outcrops of the same age in the Salt Range is surprisng; the nearest Jurassic and Cretaceous outcrops are situated about a hundred miles to the northeast but on the other side of the main range.[19] In the eastern half of the Himalaya, Mount Everest, the highest summit of all, includes sediments believed to be of either Jurassic or Triassic

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[18] Auden, Rec. 69, pt. 2, 161 (1935).

[19] The supposed Jurassic age of the unfossiliferous "Great Limestone" south of Jammu is extremely doubtful, through it has been so coloured on the latest 32 miles geological map. Wadia has shown that it is in all probability of Lower Permian (Permo-Carboniferous age). Rec. 72, pt. 2, 162 (1937).

age, but these beds in all probability belong to the Tethys zone and there are no indications of their southerly extension across the rest of the mountain belt. Possibly intermediate occurrences of fossiliferous marine Mesozoic rocks will be discovered on the higher southern slopes of the Himalaya, but so far there is no direct evidence of the Jurassic or Cretaceous sea having extended completely across what is now the Himalaya from one side to the other. This Tethys sea seems to have ended southwards along a line not very far from the present line of high peaks, trespassing to the south here and there, especially in the eastern portion of the area. Th Spiti Shales, which represent the end of the Jurassic and early part of the Cretaceous period, consist of fine detrital sediments alternating here and there with beds of coarser material. Possibly an arm of this sea extended along what is now the southern flank of the Himalaya to the Lansdowne area, though this may not have occurred till well into Cretaceous times. In the latter part of the Cretaceous period there took place a great extension of the Tethys which stretched along the whole of Tibetan zone as far as the north frontier of Sikkim and probably far to the north over much of central Tibet but not over eastern Tibet and China which formed part of the northern continent of Angaraland. A break and unconformity below the Upper Cretaceous of north Kashmir has been observed by De Terra.[20] "This formation overlaps both the southern slope of the Karakoram ranges and, at Kargil, the northern border of the central Himalaya." A slightly later phase of this break has been found above the Chikkim beds near Kalatse in Ladakh, in the eastern Tibetan plateau region and in Hundes. Signs of pre-Tertiary folding have also been noted by Medlicott in the Tibetan zone of the Garhwal Himalaya, but there appears to have been no marked susbidence along the Indo-Tibetan frontier region, where the Cretaceous deposits are largely such as would be laid down in the neighbourhood of a coast.

It is quite possible that a precursor of the Tertiary gulf along the south-western foot of the Himalaya existed before the end of the Cretaceous period. The absence of Cretaceous rocks in this part of the Himalaya—unless the outcrops in the Pillani valley are of Cretaceous and not Jurassic age—offers no support to such a suggestion, but it is easily credible that such deposits may have been completely removed by subsequent denudation or may have become entirely hidden beneath the alluvium or beneath overthrust older rocks. The Shillong plateau was at this time largely submerged beneath a sea which, so far as is known, had no connection with any gulf along what is now the Indo-Gangetic trough, but which formed part of an ocean stretching along what is today the Coromandel coast and what was then the east coast of Gondwanaland. This sea persisted over a large part of the Shillong plateau into the Eocene period but retreated after the deposition of the Sylhet limestone.

At the end of Cretaceous times there was a steady retreat of the sea from Tibet and the adjacent portion of the Himalaya. In Ladakh

[20] Rep. 16th Internat., Geol., Congr. Wash., 1933, Vol. 2, p. 864.

and Hundes the Upper Cretaceous Flysch, according to De Terra, indicates a reversion from marine calcareous to estuarine sedimentation, with intermittent marine depositon. Middlemiss found coal-bearing sandstones of Eocene age capping a Cretaceous limestone as well as older rocks with unconformity in Hazara, and De Terra adduces the appearance of weathering products such as bauxite and limonite along the plane of unconformity on top of the Upper Cretaceous Hippurite limestone as further proof of a late Cretaceous upheaval to land conditions, but there were local oscillations of the coast line as shown by the overlap of Nummulitic beds in Kashmir over older fresh-water deposits. The absence of marine Tertiary strata in the Karakoram may mean that this region has formed part of a landmass since the end of the Cretaceous period. The Cretaceous movements were accompanied by volcanic activity on a considerable scale in north Kashmir and in Hundes. These outbursts, represented by the Dras Volcanics of basic character, outlasted the Cretaceous folding and continued into Eocene times ; they must have been more or less coeval with the Deccan Trap of the Peninsula.

It may, therefore, be inferred with some degree of probability that at the end of the Mesozoic era the Himalayan region formed a broad landmass, separating the Tethys on the north from a depression on the south which for part of the time at least took the form of a marine gulf stretching from the Jammu area south-eastwards as far as Lansdowne ; the deposits of this gulf are now nearly all hidden beneath the Siwalik and Murree river silts or overthrust older rocks This landmass seems to have ended northwestwards short of the Burzil Pass, where outliers of Eocene rocks remain, and not to have reached quite so far in this direction as does the present Himalayan chain.

In visualising the sequence of events, it is natural to ask whether the first effect of the buckling of the northern margin of Gondwanaland and its intimate involution with the upraised Tethys sediments, may not have been the production of a longitudinal river corresponding in position to the much later Siwalik river. There is no evidence to show that the Tal series is marine and, if its Mesozoic age is correctly inferred, it might represent the sediments of a river flowing north-westwards along the foot of the hilly region of the Himalaya. If it ever existed, this older river was replaced by a marine gulf, and this replacement may have taken place in Cretaceous or even Jurassic times, but all we can be certain about is that the gulf existed in the Eocene-Oligocene period and was itself replaced by a younger river in Upper Tertiary times.

This Eocene-Oligocene gulf, as shown by the presence of interrupted outcrops of Nummulitic limestone, extended south-eastwards as far as the vicinity of Naini Tal. Along the northern flank of the Himayalan area was another Eocene gulf having its exit in the same northwesterly direction. Both gulfs silted up and were replaced by rivers at the beginning of the Murree period. Before the end of Oligocene times Tibet and the Himalayan region had become finally and permanently dry land.

The unity of lithological type, no less than the special sections showing conformity between most of their subdivisions, proves that the great thickness of Siwalik and Murree deposits belongs to a period of uninterrupted deposition. While, however, a continuous sequence of more or less conformable deposits was being laid down in one place, in another there occurred elevation and exposure to denudation—at least during the Siwalik epochs. It is to be concluded, therefore, that disturbance, accompanied deposition and folding in the Siwalik belt shows that the whole of the Himalaya must have advanced southwards.

"The Great Boundary Fault."—Along the whole length of the Himalaya, wherever the junction of Siwaliks with the pre-Tertiary rocks is visible, it is a reversed fault. In some places this great fault appears to form the boundary between the Siwaliks on the one side and the Subathu (Eocene-Oligocene) or Murrees on the other. West of the Beas a similar reversed fault is said to separate the Lower Tertiaries from the Mesozoic and Palaeozoic rocks of the Himalaya. It was formerly supposed that the main line of fracture marked the northern limit of deposition of the Siwalik sediments, the inference following that the movement it represents took place during the deposition of these beds. In only a very few cases were Siwaliks found on the northeast side of the fault, and in these cases it was concluded that the beds had overstepped the fault on to the pre-Tertiary slates. This dislocation was termed the "Great Boundary Fault." The idea was further elaborated by Middlemiss who showed that in the southern margin of the Kumaon and Garhwal Himalaya there are five structural zones, each bounded on the north by a large reversed fault, and each successive one showing an older rock formation as its newest member. In the outermost zone the section ranges from Nahans to Upper Siwalik conglomerates, in the next the sand-rock (Pinjor) is the newest stage seen, while in the third the latter is wanting and the section ranges up only to the Nahans; in the succeeding zone an entirely new set of rocks comes in, the newest of which is Subathu, while in the last the rocks are of unknown but at youngest Palaeozoic age. It was then concluded, with some appearance of justice, that in each case the youngest rock seen south of the fault marked approximately the period of its completion, as well as of the commencement of the next one to the south, so that the first fault, counting from the south, was ascribed to the Upper Siwalik, the second to the Middle Siwalik, the third to the close of the Nahan, and the fourth to the Subathu. A common character of these long narrow zones bounded by reversed faults is that they themselves carry along their northern border a still narrower sub-zone of the newest rock they contain. In this way arose the principal of "Boundary Faults", *i.e.*, reversed faults which were believed to mark limits of deposition.

Recent work, however, has shown that the general structure of the Himalayan foot-hills is far from being so simple and constant. Until the last fifteen or twenty years, geological work in the Himalaya had been chiefly concerned with the stratigraphical succession

and relative ages of the various rock formations exposed and, with the exception of Midlemiss's investigations, the tectonics of the range, especially those of the higher portions, were largely a matter of surmise. A systematic study of the folds and thrusts in these mountains was commenced by Guy Pilgrim and W. D. West, whose work on the Simla area showed definitely, what many had for a long time suspected, that the folds and dislocations in the Himalaya are on the same scale as—or perhaps even larger scale than—that seen in the Alps of Europe. This work, which has since been carried on by West, Wadia and Auden, is still in its infancy, and it will be possible to do little more than indicate the tendencies of their discoveries at the present immature stage of the enquiry.

In the first place, confining our attention to the highest of these so-called Boundary Faults, north of which it was supposed no Tertiary deposition had taken place, a tectonic "inlier", consisting not only of Subathu (Eocene-Oligocene) but also of Murree (Dagshai) rocks has been recognised to the northeast of it. Had it been found a short distance away from the dislocation, the general idea of the latter as a boundary of deposition would not have been seriously refuted, but the nearest edge of the "inlier" or tectonic "window", which will be further described later is situated more than 15 miles north-east of the innermost faulted Tertiary (Subathu) boundary or over 18 miles northeast of the main Murree boundary, *i.e.*, half-way between the margin of the plains and the line of central peaks and five miles nearer the latter than the hill-station of Simla. Other less striking occurrences northeast of similar faults have been noted, and the term, "Boundary Fault" would appear, thereforce to be a misnomer, unless any one of the reversed faults along the Himalayan foot-hills and the fault in the tectonic inliers should happen to be part of the same thrust. In that case the principle underlying the term "Boundary Fault" might still be true. So long as the Boundary Fault is regarded as a steep reversed fault of small hade, it is difficult to look upon it as a boundary of Murree deposition when Murrce sediments are found as much as 18 miles away from the edge of the main exposure of these beds. On the other hand, with a very low angle of thrust, it is easy to see how the overlying rocks might have been pushed many miles beyond the initial limit or boundary of the Murree deposits; the latter in that case would only be disclosed subsequently through tectonic "windows" effected by denudation. They would still lie on the down-thrust side of a fault, and the latter might still represent their "boundary" or limit. The only adjustment in our ideas is the conception of an almost horizontal boundary fault, warped itself by the folding movement, with its "roots"—if the term is permissible— well within the Lesser Himalayan ranges. It is true that the expression "Great Boundary Fault" or "Main Boundary Fault" has been used occasionally for different faults by different observers,[21] but the "Main Boundary Fault" of Middlemiss appears to be identical with Auden's "Krol Thrust" which has been recognised not only in the Simla and Chakrata areas

[21] Rec. 71, pt. 4, 416 (1937).

but in Nepal and further eastwards in the Darjeeling area.[22] This thrust, therefore, is evidently widespread and important feature; nonetheless, the term "Main Boundary Fault", as applied to any particular dislocation, is perhaps best discarded. There is little doubt that some of the thrusting in the Himalaya took place during as well as after the Miocene period, and the front of the lowest thrust must have raised a long, more or less continuous barrier, more or less effective in limiting the northward extension of deposition. Such barrier or barriers, raised in some places by more than one fault, must have functioned throughout and after the Murree-Siwalik period.

Tectonic features.—*Nappe* structure in the Himalaya is the rule rather than the exception, and there are several large thrust-faults which have in many cases themselves been plicated by subsequent folding, and whose trace is a highly irregular line meandering in all directions though in most cases preserving a general N.W.-S.E. tendency.

At this stage it is possible to make a few general statements concerning the structure of the Himalaya. Allusions to the subject have been made when describing the rocks concerned—the most suitable place for such allusion, perhaps, in view of the unfinished state of our investigation—but the following is a brief review of some of the features recorded by the four officers mentioned, beginning with Kashmir.

The principal tectonic feature of Kashmir is what Wadia has called the Panjal Thrust-plane, which has been traced along the southwest flank of the Pir Panjal for 120 miles as far as Thana Mandi and has been recognised 75 miles still further to the southeast at Dalhousie.[23] At a comparatively low angle, usually between 15° and 30° this thrust has brought the older rocks of what has been called the "Kashmir nappe" on to a younger zone of rocks, which forms the lower and sometimes basal portion of the Pir Panjal range; this younger zone has been named by Wadia the "autochthonous zone", although it has itself been thrust up a somewhat steeper plane over Murree, Nummlitic, Cretaceous and sometimes older rocks. In western Punch the Panjal Thrust shows a uniform inclination to the northeast and does not seem to have suffered plication to an appreciable extent; its trace is here the usual irregular meandering line. South-eastwards, towards the Banihal Pass, it becomes steep and even reversed in places, owing to late compressional movement.[24]

The autochthonous zone, usually from three to four miles in width and composed of Nummulitic sediments with inliers of the Punjab Volcanics and Permo-Triassic beds, is described as an imbricated system of sheared isoclinal folds, inverted and truncated. Across this zone and the next one below it—the Murree zone—for a distance ranging up to 30 miles, a dip to the northeast is maintained. The

[22] Wadia and Auden, Mem. 73, 123 (1939).

[23] Rec. 68, pt. 2, 171 (1934).

[24] Rec. 72, pt. 1, 75 (1937).

Murree zone, whose rocks are not far from the vertical, includes a few inliers of "Great Limestone" (probably Lower Permian) and Nummulitic. This zone, some 18-24 miles wide, is separated from the Siwaliks to the southwest by a deep reversed fault throughout most but not all of the contact;[25] where the contact is not faulted Wadia described it as occuring in an ordinary basin of deposition obscured by local faulting and overlap.[26]

The Kashmir *nappe*, above the autochthonous zone, is made up of Purana slates and schists forming two major axes of orogenic upheaval which carry between them a synclinorium of Palaeozoic and Mesozoic sediments; the two axes of upheaval occupy the Pir Panjal to the southwest and the more disturbed range of mountains known as the North Kashmir range to the northeast. The Pir Panjal has a peculiar uniformity both as a physiographical feature as well as in its stratigraphy and structure. From the watershed line of its crests, which departs very little from the prevailing strike of the rocks, to the thrust-plane along its southwestern foot, the range, with its subordinate hills, is of orthoclinal type, according to Wadia, with steep cliffs facing south-westwards and gentle slopes in the opposite direction. The middle portion of the *nappe* zone is the open Kashmir basin which, with its uninverted folding and no pronounced shearing or reversed faulting, is in strong contrast to the autochthonous zone below. North-eastwards, however, the intensity of folding increases and inversion is again seen in the folds along the northeastern rim of the synclinorium; the limit of the latter in this direction is a reversed fault of great lateral displacement, throwing the Salkhalas over the top of the Trias. There are many smaller faults in the Kashmir valley, and the general strike is variable; in spite of the proximity to the Jhelum syntaxis, some of the fold axes have an E.-W. direction. The Nanga Parbat region is one not only of extreme stress metamorphism but also of great tectonic disturbance, characterised by imbricated sytems of puckered and reversed folds, severed from each other by many thrust and shear planes.[27]

From the Kashmir basin to the valley of the Indus the structure has been described by De Terra[28] who provisionally recognises five tectonic zones. The first or outermost of these, apparently succeeding Wadia's Kashmir *nappe* to the northeast, is described as another "autochthonous zone" occupied by the Basmai anticline on the northern slopes of the Kolahoi *massif*, and a somewhat displaced syncline of Permian and Triassic rocks. This is followed by a complex thrust zone of tightly compressed formations, exposed in the Zoji La, and composed of Trias, gneissose granite and green schists

[25] Some outcrops mapped at first as Siwalik on the inside of this fault, which is supposed to be a portion of the so-called "Main Boundary Fault", belong most likely to the Upper Murrees The reversed fault at Kotli, whose inclination was measured by Middlemiss and found to be 12°—15° at the exposed surface, was found by Wadia to end north-westwards in an anticlinal fold (Rec. 67, pt. 4. 447 (1934)).

[26] Mem. 51, 271 (1928).

[27] Wadia, Rec. 66, pt. 2, 227 (1932).

[28] Mem. Connect. Acad., 8, Art. 2, 61 (1935).

of unknown age. Next comes a syncline of Triassic strata faulted and partially overthrust by the following zone, which consists of a synclinal belt of the Indus Flysch, Eocene and the Dras Volcanics. The fifth or final zone is described as an autochthonous crystalline complex of granite and diorite. De Terra notes that each zone appears to be separated from the next by a major shear or thrust plane. North-eastwards the dips of these thrust-planes decrease until in the Gamru syncline of Triassic beds forming the third one it is parallel to the normal dip of the rocks; this steepening of the thrust planes in a southwest direction is thought to be due to subsequent movement. The Gamru synclinorium includes a number of recumbent folds with the open limbs directed north-eastwards. In the Karakoram the folding is much steeper than it is in the Kashmir Himalaya. Between the Kashmir and Indus valleys De Terra records evidence of gentle warping long after the Tertiary orogeny and even after the intra-Pleistocene folding.

Before continuing our resume of the recent work on Himalayan tectonics, it will be convenient to consider the disposal of the rocks round the sharp syntactical angle between the western end of the Himalaya proper and the mountains which form its continuation on the other side of the Jhelum and Indus, as well as the folding and thrusting in these continuing ranges, in the Potwar and in the Salt Range.

The Jhelum syntaxis is not the point of mutual interference between two separate wave-fronts coming from different directions, as was at one time suggested, but is a point of obstruction in a single wave-front coming from one direction. It is an acute bend which affects the trend of the mountains and the lie of geological formations to a width of some 300 miles. from the edge of the Indo-Gangetic alluvium near Mangla to beyond the central axis of the mountain chain as far north as the foot of the Pamirs in latitude 37° N. This bend attains its maximum sharpness between the Kunhar and Kishenganga rivers, where it becomes as almost parallel-sided hairpin loop, the Jhelum here following the N.-S. strike of the beds. Both to the north and to the south of the loop, the angle of convergence of the fold axes gradually increases, but as far north as latitude 37° there is still a marked change in the direction of the strike lines round the large granite *massif* of the Pamirs which may be a visible portion of the obstructive horst promontory which produced the syntaxis; on the east side of this is the Karakoram curving first south-eastwards and then E.S.E.'wards, while on the west is the Hindu Kush with a general W.S.W. course. Nanga Parbat is another pivotal point further south; from Astor northwards the rocks on the two sides of the syntactical bend have been forced into parallelism.[29] but on the Kashmir side soon swerve south-eastwards in the Baltistan and Zanskar mountains. West of Nanga Parbat the beds take up a south-westerly strike, the mountains of Hazara being structurally and stratigraphically a continuation of corresponding ranges in the Himalaya.[30]

[29] Rec. 66, pt. 1, 124 (1932).
[30] Rec. 45, pt. 4, 273, 320 (1915).

A noteworthy point in the syntactical area is that the Murree rocks of the outer zone or foreland show scarcely any trace of deformation or stress metamorphism ; as Wadia remarks, this can only be accounted for on the assumption that they rest upon a rigid hidden basement which has taken the brunt of the compression.[31] This zone is separated from the autochthonous zone by a steep thrust. The autochthonous zone has been thrown into one or more recumbent anticlines and has been much encroached upon by the overriding *nappe* zone ; from the latter the autochthonous zone is separated by a continuation of the Panjal Thrust, a flatter—sometimes almost horizontal—and more intense dislocation than the outer thrust just described. No mylonisation has been observed by Wadia along the trace of the Panjal Thrust. On both sides of the syntactical loop, the *nappe* zone of old Salkhala rocks has in places been pushed completely over the autochthonous zone and abuts on to the soft, coarse Murrees. From the north to the west side of the loop, the autochthonous zone not only narrows but gradually steepens to verticality before disappearing below Muzaffarabad.

On the west side of the Jhelum syntaxis, the wide sedimentary terrain of Hazara is an expansion of the autochthonous zone and the Salt Range is a repetition of it brought about by an outlying fold. The Hazara rocks have a persistent northwesterly dip except along the southern borders where for some forty miles in the broad belt of the Margala hills the fold systems of the Cretaceous and Nummulitic have been overthrown and show a southeasterly or southerly dip.

West of the syntaxis, the effects of the compressional force which we have agreed to speak of as coming from the north are less concentrated than they are in the Himalaya, and are spread over a wider area. This more uniform dissipation of the plicatory impulse can be seen in the Potwar area, the North-West Frontier and Afghanistan, and still more in the mountain arcs of Baluchistan. Beyond the Jhelum syntaxis, the trough broadens and is divided longitudinally by the outlying rock-waves of the Salt Range and its trans-Indus continuation. In Afghanistan the structure has not been worked out in detail but in this country and Baluchistan the trough area appears to have broadened exceedingly, while the Siwalik sediments have become embroiled in the reduplication of the trough and the interrupting rock-waves.

Nappe structure may possibly exist in the unexplored country between Chitral and Hazara, and thrusting has been recorded on an appreciable scale in the Salt Range ; reversed faulting and folding are, in fact, common in the northern Punjab and North-West Frontier. From the Jhelum to Waziristan part of the compression seems to have been taken up by the thrusts which have affected the Salt Range rocks and those of its trans-Indus continuation. Perhaps for this reason, the structure of Hazara is different in some important respects from that of equivalent zones in the Himalaya. While in the Simla area, for instance, whole rock groups have been thrust almost horizontally over one another, the corresponding zone in Hazara is

[31] Rec. 65, pt. 2, 216 (1931).

characterised by parallel bands of highly compressed rocks, approaching verticality, upthrust along a number of more or less parallel reversed faults.[32] From Waziristan south-westwards, folding and dislocation become less severe, and the same remark will probably be found to apply to the Burmese folding at the other end of the Himalayan chain. It would appear as if the Himalaya had borne the brunt of the impulse from the north, and this may be why folding and faulting are so much more severe in this region than in the more distant, more protected and more obliquely exposed edges of the Peninsular shield in Baluchistan and Burma. Translated into the parlance of the Continental Drift theory, the northern margin of the Gondwana continent, with its sharp Muzaffarabad promontory and its equally acute northeastern Assam corner, was first to impinge against the marine sediments fringing Angaraland. As the one landmass thrust its way into and under these coastal sediments the resultant excessive shortening was accompanied by the lapping of the northern continent round the sides of the southern. In these enlapped regions of Baluchistan and Burma, the pre-Tertiary rocks for the most part are similar to those found in the Tibetan zone and are extra-Peninsular in the true sense of the word. None of the ancient rock-series of Gondwanaland has been recognised as such in either of these regions, though the old Chaung Magyi beds of Burma are considered by some authorities to represent the folded margin of this continent.

West of the Jhelum, no physiographical subdivision precisely equivalent to the Sub-Himalaya, the Lesser Himalaya, the Great Himalaya and the Tibetan Himalaya can be distinguished as such. The place of the sub-Himalaya is taken by the Potwar Plateau, and in the Salt Range, along its southern margin, portions of the sequence seen in Kashmir and in the Kala Chitta and Hazara ranges are repeated near the base of the hills. In Hazara, the lowest member of the Tertiary is intimately infolded with the Tibetan facies of the Trias, Jurassic and Cretaceous, while the three latter sedimentary systems are associated higher up the hills with the great series of unfossiliferous slates similar to that seen in the Lesser and Great Himalaya. Middlemiss, however, divides the country into four tectonic belts, which in general show an increase in metamorphism with elevation: these are:

N.N.W.

(a) Crystalline and Metamorphic zone;

(b) Slate or Abbottabad zone;

(c) Nummulitic zone;

(d) Upper Tertiary zone.

S.S.E.

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[32] Rec. 65, pt. 1, 125 (1931).

Each of these zones is said to differ from the next by the varying levels at which any common formation occurs in the sequence exposed; for example, the Trias, while occupying a rather high position in the sequence of the Slate zone, holds a much lower place in the Nummulitic zone, and is unexposed in the Upper Tertiary zone. The contrast, however. breaks down in the country east and southeast of Abbottabad where the rocks exposed, although occurring in zone (b), belong mostly to the formations characterising zone (c). Accompanying an increase in metamorphism from southeast to northwest is a general increase of disturbance due to compression.[33] The boundary between (a) and (b) is either a single well-marked reversed fault, a plexus of faults, or a line of excessive folding; southwestwards this boundary becomes blurred and there is a gradual passage from the slates to the crystalline schists. Zone (b) is separated from zone (c) by a remarkably continuous reversed fault, which, in the direction of the Jhelum syntaxis, approaches very close to another well marked continuous reversed fault between zone (c) and zone (d) along the foot of the Margala hills; the former performs much the same function as the Panjal Thrust on the east side of the syntaxis, bringing the ancient slates over the Nummulitics, but the structural pattern of the country is by no means simple, and large exposures of Nummulitic rocks occur above this middle thrust as well as below it. Many other smaller strike faults characterise the Hazara district.

Westwards, the lowest of the three main faults just described is continued *en echelon* along the foot of the Kala Chitta hills. The latter consist of highly compressed and contorted beds, mostly of massive Nummulitic limestones but partly of Mesozoic strata, all of which have been thrust southwards over the Murrees. This thrust has been traced westwards across the Indus through Kohat. The northern part of the Potwar Plateau, south of the Kala Chitta thrust, consists of a belt, some 20 miles wide, of Murree rocks folded for the most part isoclinally and dipping steeply tc the north, with a few tortuous inliers of Chharat beds (Upper Nummulitic) and one long narrow outcrop of the Hill Limestone (Lower Nummulitic) accompanied by a thin development of the Chharats. This latter inlier is the well known Khair-i-Murat ridge, which is bounded along its southern foot by the thrust-plane whose continuation forms the southern boundary of the Murree zone, and passes westwards through Mianwala village. Towards the Indus, the folding in the Murree zone becomes more open and less isoclinal. South of the Mianwala fault. Pinfold defines a faulted zone of about 10 miles width, in which the structure is still more open. In this zone the anticlines, though all of them closely folded and in most cases laregly replaced by strike faults, are separated from each other by open synclinal basins. The most southerly of these faults passes close to Chhab and has been traced to the Indus. South of the Chhab fault comes a zone of pronounced but open folding, in which faulting plays only a minor part;

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[33] Middlemiss, Mem. 26, 264 (1896).

forming part of this zone are the two oil-field domes of Khaur and Dhulian.[34] The open folds of this region merge southwards into the broad Sohan syncline, which has already been described (p. 1927).[35]

It has been shown by E. R. Gee that the structure of the Salt Range is by no means so simple and regular as it was at one time supposed to be and as some sections might lead one to infer. The succession is complicated not only by three or four major unconformities but also by structural disturbances of late Tertiary to sub-Recent age. Throughout the greater part of the range these folds, overfolds and thrusts follow a general E.-W. trend. In the west, however, the tectonic grain swings rapidly up towards the N.N.W. while eastwards, in the Karangal and Diljaba ridges it swings towards the N.E. In the extreme east, *i.e.*, in the Chambal and Jogi Tilla ridges the strike of the rocks is abruptly dislocated; in the former it follows a curved arc having a general N.-S. direction, in the latter it runs N.E.-S.W., parallel to that of the Diljaba ridge.

The rocks exposed in the Salt Range are mostly of Extra-peninsular facies but include types reminiscent of Peninsular formations such as the Vindhyan and Talchir; Gee has also suggested certain correlations with the Kala Chitta rocks. After the late Mesozoic uplift, widespread subsidence affected most of the Salt Range area, admitting the Ranikot sea which stretched north-westwards over northern Kohat and northwards over part of the Kala Chitta; lagoonal conditions prevailed in the eastern part of the Salt Range as well as in parts of the Kala Chitta, as indicated by the Palaeocene coal of these areas. Following some oscillations, a general uplift of the Salt Range area took place in late Eocene or early Oligocene times, but it was not till after the Murree period that the main orogenic movements were inaugurated to which the Range and its trans-Indus continuation owe their present form and structure. There is reason to believe that the Salt Range at the commencement of the Upper Siwalik epoch had become an elevated tract undergoing denudation. As already remarked, some of the folds and thrusts were oblique to the main lines of plication and the general trend of the range; these transverse effects may have been due to squeezing between the advance of the Himalaya from the northeast, the Hazara hills from the north and the Sulaiman range from the west. Normal faulting, according to Gee, plays but a minor role in the structure of the Salt Range. In some cases the Salt Marl and the gypsum provided suitable lubricating media for thrusting, and the Lavender Clay stage at the top of the Carboniferous was another formation over which sliding and disharmonious folding took place.

Concurrently with the rise of the Salt Range, a geosynclinal tract was formed in the Potwar to the north and the Kohat and Bannu areas to the northwest and west. In this geocyncline the Murree and Siwalik fluviatile sediments were laid down during the period of relative quiescence which followed in mid-Tertiary and early Upper

[34] Rec. 49, pt. 3, 141 (1918).

[35] For sections across this part of the Punjab see Dr. Cotter's memoirs, 55, pts. 13-18.

Tertiary times. During a considerable part of this period, the relatively elevated Salt Range and the trans-Indus ranges were eroded to a greater or less extent, especially towards the south in the former area and towards the southeast in the latter. In the more elevated tracts denudation continued in places well into Siwalik times, exposing a land surface composed of Palaeozoic and Mesozoic rocks. During the erosion of this land surface, there was transgressive deposition thereon of Middle Siwalik sediments.

From late Siwalik to sub-Recent times, a second period of acute earth movement from the same directions prevailed. That such movement continued into the Recent period is shown by the thrusting of Nummulitic limestones over deposits of sub-Recent age ; it is probable that, as in the Himalaya, such movement is still taking place. The effect of the renewal of the orogenic forces was the acute folding and shearing of the strata which formed parts of the Potwar-Kohat-Bannu syncline ; similar folding and duplication by thrusting also occurred near the outer edges of the Salt Range and trans-Indus hills. "Striking evidence of the very recent age of certain of these acute earth movements is afforded not only by the steeply dipping post-Siwalik sands, clays and conglomerates of the Salt Range plateau, but also by the occurrence of relatively very recent beds intercalated within the gypseous marl stage near the base of the scarp in the eastern part of the cis-Indus range. Here, in close association with this gypseous marl, we find beds of red clay and soft sandstone, including boulders of gypsum, dolomite and Khewra trap (derived from the Saline series), Purple Sandstone and Magnesian Sandstone. The gypseous marl is often greatly disturbed—brecciated, sheared and foliated—and the associated more recent deposits also show high dips in general conformity with those of the normal marl. These very recent deposits vary from thin lenticular inclusions up to more regular sediments over 200 feet in thickness."[36] Gee concludes that these beds, derived by erosion from the Salt Range scarp and deposited at the foot of the range, were caught up among the strata of the gypseous marl stage during the above mentioned period of acute post-Tertiary earth movement. Faulted fan deposits of sub-Recent material and a dissected fault scarp have been noted by De Terra near Rukhla.[37]

Structural evidence supporting the presence of thrusting is seen in the widespread brecciation and slickensiding of the Purple Sandstone (Cambrian or pre-Cambrian) near its junction with the massive gypsum that forms the upper member of the Saline series ; beneath the junction the gypsum bands are often contorted and the hard cherty and dolomitic layers definitely brecciated. "Still more convincing is the evidence afforded by the Talchir Boulder bed in the vicinity of its junction with the underlying gypsum. Throughout a distance of about 30 miles in the western part of the Salt Range, this conglomerate directly overlies the Saline series and there are numerous clear sections showing the junction of the two series. In a large

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[36] E. R. Gee. Private communication.

[37] Rep. 16th Internat. Geol. Congr. Wash., 1933, Vol. 2, 867.

number of these exposures, throughout a thickness varying up to about 20 feet above the junction, the stratification of the shale matrix has been obliterated and the majority of the included boulders, consisting of hard granites, gneisses, quartzites, rhyolites, etc., have been crushed and sheared, the sheared fragments, being often held together by growths of secondary gypsum brought up by capillarity from the underlying Saline series. In those sections in the eastern and middle parts of the Salt Range, where the boulder-bed rests on the early Palaeozoic or pre-Cambrian strata, no evidence of such disturbance is observed."

Westwards, the line of the northern boundary of the Nummulitic zone of Hazara is hidden beneath recent accumulations of the Hurroh and Indus rivers until the Cherat hills are reached, when its normal faulted boundary again appears ;[38] as in Hazara, the Nummulitic zone here shows the same absence of exposure of the ancient slates. In the Safed Koh still further west a similar zonal arrangement can be made out. Here, while the old metamorphic and Palaeozoic rocks are found only in the northern belt of the northern skirting range, the younger systems of the Mesozoic are only seen in the southern skirting range ; between these zones, *i.e.*, in the central range and the southern part of the northern skirting range, the rocks consist of older Palaeozoic with included strips possibly of older Mesozoic.

On this further side of the Indus, west of Kalabagh, is another syntactical area, separating the arc of the Salt Range from that of its trans-Indus continuation. It is occupied by the Kohat salt fields and is characterised by twisted, fold-faulted anticlines. Another occurs in Waziristan somewhere between Bannu and Jandola, beyond which comes the system of arcs forming the Sulaiman, Bugti and Marri hills and the ranges of Loralai and Zhob. The Sulaiman range is of simple structure, forming the eastern limb of a large anticline. In this and the other hills of northern Baluchistan there is a more or less normal succession from Jurassic to Cretaceous, Eocene, Gaj and Siwalik, and a general absence of thrusting. There follows another well marked syntaxis across the line joining Pishin and Sibi, occupied by a deep embayment of Upper Tertiary and Indus alluvium. Next come the broad, sweeping, arcuate ranges and outcrops of southern Baluchistan, swinging north-westwards into Persia. In southern Baluchistan there is the same normal sequence of Mesozoic and Tertiary series in comparatively simple folds. It is possible that *nappe* structure exists along the inner side of the arcs of northern and southern Baluchistan, *i.e.*, in southern Afghanistan, but it is not found on the Indian side of the frontier. A conspicuous *nappe* zone has been recognised in the Persian highlands.[39]

[38] Middlemiss, Mem. 26, 264 (1896).

[39] Ras Mussendum, the acute northwardly projecting promontory of 'Oman in the Straits of Hormuz at the entrance to the Persian Gulf represents perhaps an obstructive point similar to the syntaxes of India and opposed to the same Tertiary movement; none of the rocks actually exposed here are older than the Carboniferous, but there may be a foundation of something older.

Returning now to the Himalaya we found, according to S. K. Roy, that in Mandi State, some forty miles northwest of Simla, one of the Lower thrusts—the so-called "Main Boundary Fault"—has brought large *klippen* of pink dolomitic marble, belonging probably to the Blaini or Krol series, over beds which for the most part are Middle or Lower Siwalik sandstones, Kasauli beds, or rock-salt of Eocene age, but in some cases are metamorphosed trap or Palaeozoic slates; the basal portion of one of these exotic masses is a conglomerate having the appearance of a glacial deposit. The rootless nature of the dolomitic marble, which is usually highly folded, puckered or crushed, is especially well seen at Margal, three or four miles north of Mandi town. The Tertiary sediments along the faulted contact are usually steeply inclined and in their unmetamorphosed condition show a marked contrast to the *kilppen*; the roots of the latter are presumed to occur in Kulu to the northeast, sixteen or twenty miles away.[40]

Next to be considered is the Simla and Chakrata area where most of the recent work has been concentrated. North-east of Solon, which lies in a belt of Subathu and Krol rocks, Pilgrim and West proved the existence of four important thrust-planes, dividing the terrain into comparatively thin slices. North of Solon, for example, the traces of all four thrusts lie within an aggregate width of four miles. The thrust-planes themselves have yielded appreciably to compressional forces and have been warped with the strata they separate into pseudo-synclines and pseudo-anticlines. Two additional major thrusts have been encountered by Auden at slightly lower levels—the Krol and the Nahan thrusts—the former of which has been traced for many miles.

The fossiliferous sedimentary rocks found in Kashmir above the Kashmir *Nappe* are not seen in the Simla-Chakrata area in a corresponding position, *i.e.*, above what is believed to be the equivalent of the Panjal Thrust; such fossiliferous rocks are in this section of the Himalaya confined to the Tibetan zone, and if they ever existed on the south side of the main Himalayan axis, have been either metamorphosed beyond identification, completely buried beneath thrusts, or entirely denuded away.

The lower portion of the Lesser Himalaya, from the country below Simla to the country below Chakrata, has been surveyed in detail by Auden, who alludes to it as the Krol Belt, a *nappe* area of extreme structural complexity, amounting to pure chaos; it corresponds to the autochthonous zone of Kashmir. The rocks of this belt, although overturned in places, have not been bent into recumbent folds. Broadly speaking, the belt comprises two contiguous thrust-bound synclines, involving Krol rocks in the west and both Krol and Tal rocks in the east, resting throughout on a foundation of Jaunsars and Simla Slates which have shared in the movement.[41] The two synclinal tracts have been called the Nigali syncline to the north-east,

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[40] Quart. Journ. Geol. Min. & Met. Soc. Ind., 5, No. 4, 131 (1933).
[41] Auden, Rec. 67, pt. 4, 430 (1934).

named after the magnificent ridge running south from the vicinity of the Guma peak, and the Krol Hill-Kamli Dhar syncline or synclinorium to the southwest.

The Krol Hill-Kamli Dhar sequence of folds is really a complex of synclines, with marked inversion of its beds, and is bounded along its southwest border by a large thrust known as the Krol Thrust, the equivalent of the Murree Thrust in Kashmir ;[42] approximately this fault forms the boundary between the Krols and their foundation rocks on the one hand and the main belt of Tertiaries on the other. Along the upthrust side of the fault are exposures varying from Infra-Krol and Blaini to Jaunsar and Mandhali rocks, while the downthrust side consists of either Subathus, Dagshais, Kasaulis or Nahans. The inclination of this thrust is in some palces quite low; near Kalsi, for example, it is between 25° and 35°. Like most other thrust-planes of this region, however, its inclination varies widely and is a matter of purely local interest; between Narag and Dadahu it is very steep and northwest of Barog Railway Station it has been inverted and is now inclined towards the southwest instead of towards the north-east. The Krol Thrust is a feature of some magnitude and, in the Giri river, 21½ miles east of Nahan, it overlaps the Nahan Thrust; the latter is a dislocation of lower tectonic position than the Krol Thrust, and to the south of Dadahu, has brought the Subathu beds—themselves overthrust by the Infra-Krol and Blaini—on to the Nahans. Eastwards, where the overlap of the thrusts takes place, the Infra-Krols are brought directly upon the Nahans, the intervening slice of Subathu rocks having tailed out and disappeared. The Krol Thrust, while varying considerably in its observed inclination, is generally less steep than the Nahan Thrust. Auden suggests that the extensive lateral movement of older over younger rocks brought about by the Krol and other thrusts may be responsible for the change in strike which occurs near Dadahu, since from this village the rocks strike north-westwards to the hills below Simla on the one side, while on the other they veer to an easterly course towards Kalsi and beyond. Whether this is the case or not, it cannot be disputed that the thrusts in this portion of the Himalaya have caused many vagaries in the normal strike of the rocks and folds. Northeast of Dagshai, the Krol Thrust is believed to have been acutely folded with the rocks of the Pachmanda syncline and the adjacent anticline ;[43] the latter, in fact, composed of Subathu beds on a core of Simla Slates, is exposed as a tectonic window below the thrust, like other small outcrops of Subathus in the neighbourhood of Solon.

The northeastern boundary of the Krol Hill-Kamli Dhar synclinal complex is the Giri Thrust separating it from the Nigali syncline. The Giri is another well marked thrust which has been traced by Auden from the Gambhar river, southwest of Jutogh, where it was first recognised by Pilgrim and West, to about seven miles east of Dadahu; here it first splits up into several minor thrusts and then

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[42] Identified by some of the earlier observers with the so-called "Main Boundary Fault".

[43] Rec. 67, Pl. 25, Sect. 1 (1934).

dies out in an anticlinal fold. The trace of this thrust has thus been identified at points 42 miles apart and its northwestern extension has not yet been completely followed. Northwest of Kandaghat the thrust is steep, Simla Slates being brought up against Jaunsars ; along the Ashni river the inclination becomes gentler, Simla Slates being thrust first over Infra-Krols and then over themselves. This thrust has also suffered inversion in one place. The Giri Thrust is described by Auden as having caused more havoc than the Krol since it has pushed the unyielding slates of the Jaunsar and Simla series over the incompetent Krol limestones, producing minor thrusts and inversion therein. The incompetency of the rapid alternations of limestone and shale which make up the Krol and Infra-Krol sequence is a feature of the Krol Belt as a whole and is responsible for the intricate twisting and irregular folding and overfolding of the beds. From this character Auden concludes that these younger beds had not been stiffened by any metamorphism previous to the Tertiary orogenies.

A few miles below Chakrata is a thrust-plane separating Mandhalis and Jaunsars from some beds which may eventually prove to be the equivalents of the Simla Slates. This thrust, provisionally designated the Tons Thrust, is a well marked dislocation which, instead of dipping to the northeast, has an inclination to the southwest and south. Should it prove to be a continuation of the Krol Thrust, the great syncline of Jaunsar rocks overlain by Krols and Tals would have to be regarded as a *nappe* resting on a folded thrust-plane.[44]

The inner boundary of the Nigali syncline is the Chail Thrust, which has been traced by Pilgrim and West for many miles and is one of the most important and widespread thrusts of the Simla area. It is seen running north-westwards along the left flank of the Ashni river channel and in this direction to Halog, bringing Chail rocks up over the Jaunsar or the Blaini. The structure along this section is unusually regular, and the trace of the Chail Thrust is for the most part a very tortuous one, winding well into the hills. In the Deoban area mylonites have been found beneath the Chail Thrust ;[45] as a rule such phenomena appear to be uncommon beneath Himalayan thrusts. North-westwards, the Chail Thrust is seen to extend past Dalhousie and is probably identical with the Panjal Thrust of Kashmir.[46]

In the Chakrata area the Chails, with a low northerly dip, are seen thrust over less highly metamorphosed rocks, consisting of either Mandhalis (upper part of the Deoban series) or Deoban Limestone ; the rocks beneath the thrust usually display a high dip and are often considerably folded, but the strike is usually much the same above and below the thrust.

Next to be considered is an extremely interesting tectonic "window" which occurs below a thrust believed to be the equivalent of

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[44] Auden, Rec. 67, pt. 4, 440 (1934).

[45] Rec. 65, pt. 1, 130 (1931).

[46] Rec. 69, pt. 1, 77 (1935).

the Giri, and which is the subject of a recent paper by West.[47] It is found in the Shali area northeast of Simla, where the trace of the thrust has been followed for three-quarters of a circle around the Shali ridge, enclosing a "window" of younger beds laid bare by the denudation of the overlying *nappe* of more ancient rocks; throughout the other quarter of the circle, the trace has been covered by talus and affected by a fault, otherwise it would no doubt be found to form an unbroken circle. Underneath this large hole in the *nappe* the rocks are disposed in a dome-like swelling on the eastern end of an anticline and comprise the following formations from above downwards: Dagshai beds; Sabathu beds; Madhan Slates; members of the Shali series (Shali quartzite, Upper Shali limestone, Shali slates, Lower Shali limestone and Khaira quartzites), which may eventually prove to be homotaxial with the Krol series. The centre of the dome lies in the Sutlej valley, north of the Shali peak, and a general quaquaversal dip is seen, not only in these beds, but also in the overthrust sheet of Chail beds; the latter show warping in conformation with the dome structure of the rocks below but there is at the same time a marked distinction between the gently warped, unfolded nature and locally disturbed condition of the underlying rocks. The latter, from their resemblances and tectonic position, as we have observed, may belong to the *wurzel-region* of the Krol *nappe* which has been described above. The Chail rocks above the Krol, Madhan and Tertiary beds have themselves been forced many miles southwards and show a higher grade of metamorphism than the over-ridden beds. In the case of pelitic sediments, this is well seen where the Chail slates overlie the Shali slates; while the former are phyllites or silky schistose slates which have clearly undergone preliminary recrystallisation of an epigrade and are full of vein quartz, the latter are either simple clay slates with little or no metamorphism, or true slates with a cleavage but nothing more. The contrast between the rocks above and below the thrust is still more marked where the underlying rocks belong to the Subathu or Dagshai formations and are still in the condition of shales though rather jointed, with well preserved fossils. With regard to psammitic types, while the Chails include true quartzites or quartz-schists, the Tertiary equivalents are sandstones and rarely quartzites. Signs of crushing are not wanting on both sides of the thrust, especially where the lower surface is that of a massaive rock; the Lower Shali limestone for instance, shows laminated and platy mylonite below a few inches of crushed Chail slates. Within the window is a small and probably quite thin *klippe* of Chail beds, resting discordantly partly on Madhan slates, partly on Subathus and partly on Dagshai beds; this is seen around Kathnol and is roughly circular. Occurrences of Shali limestone within the Chail beds of the *klippe* are thought to be fragments thrust into or caught up by the Chail sheet as it moved over the area. The quartz veins, found throughout the Chails of this area and in some places amounting to almost half the total rock, are, in the opinion of West, derived from the thick sill of ortho-gneiss which has intruded the higher parts of the Chail series.

[47] Rec. 74, pt. 1, 133 (1939).

The Shali "window" is not without complications. A minor thrust occurs at Chaba. On the north side of the Nauti Khad the Chail *nappe* has "plunged"; the front part of the Chail sheet appears to have met with more obstruction than the hinder part and to have been over-ridden to some extent by the latter, the result being a backward buckling. Consequently, in the southern flank of the Nauti Khad, the beds beneath the thrust show signs of intense disturbance; the Shali limestone, Shali quartzite and Madhan slates have here been bent into recumbent folds of small amplitude, the middle limbs usually sheared and replaced by a minor thrust, and the quartzite and limestone in places highly crushed and brecciated. West also brings forward evidence to show that slices of Shali limestone and other rocks have been torn off the main Shali outcrop and dragged along the Shali Thrust until they lie upon the autochthonous Tertiary rocks. The Shali Thrust is again seen at Tatapani in the Sutlej valley west of the Shali area, whence it has been followed westwards and southwards and appears to be continuous with the Giri Thrust. At Tatapani the Chails overlie the Shalis, and the thrust junction is marked by the well known hot springs.

The area of Jutogh beds, at the centre of which is situated the military station of that name, is regarded by West as a large *klippe* composed of a flat recumbent fold whose roots have been identified north of the Sutlej valley; the thrust beneath it has been called the Jutogh Thrust and is higher in the tectonic scale than the Sali Thrust.

A glance at any sufficiently small-scale geological map might arouse the impression that the well marked bulge towards the south-west of the outcrop of the pre-Tertiary rocks, between Mandi and Dehra represents a more advanced section of thrusting—a section in fact, where the older rocks have ridden over the Tertiaries in the direction of the plains to a greater extent than they have on either side. The two re-entrants of the Tertiary outcrops on each side of the bulge, however, appear to be erosional rather than tectonic in origin.[48]

The structure of the Garhwal Himalaya is the subject of a recent paper by J. B. Auden,[49] who divides the area into: (i) an autochthonous unit with a base of rocks which are probably the Simla Slates and are overlain by Subathus, Murrees and Siwaliks; (ii) the Krol *nappe* or Krol Belt, whose westerly continuation has been described above, and which has been thrust over the autochthonous unit; (iii) the Garhwal *nappe* thrust over the Krol *nappe*; (iv) the main Himalayan range of varied make-up; (v) the granite zone north of the main range containing intrusives into the para-gneisses and schists of the main range; and (vi) the Tethys zone of fossiliferous sediments.

The autochthonous zone of Garhwal occurs well within the mountains and is characterised by numerous faults and thrusts, none of which appears to be of premier magnitude.

Some 20,000 feet of beds, ranging from the Chandpur to the Tal series, are involved in the Krol *nappe*, the succession being a normal

[48] Wadia & Auden, Mem. 73, 145 (1939).
[49] Rec. 71, pt. 4, 407 (1937).

uninverted one, as shown by the current-bedding planes. Two small "windows" in the *nappe* expose Subathus and Simla slates; the Subathu shales in places show a highly sheared, pseudo-schistose texture, and scattered haphazard in them are blocks of highly shattered quartzite the surfaces of which have been glazed by friction. The lowest member of the *nappe* is made up of the unmetamorphosed Chandpur beds, which are probably not very different in age from the Simla Slates they over-ride. In Auden's opinion, the displacement of the Krol *nappe* is likely to be at least 20 miles.

The minimum distance of translation of the main Garhwal *nappe* may be about 50 miles. Forming parts of the Garhwal *nappes*, two small *klippen* or tectonic "outliers" have been noted at Satengal and Banali, and another somewhat more advanced and larger *klippe*, covering some 240 square miles, carries the hill station of Lansdowne The Dudatoli-Dwarahat-Ranikhet-Almora region, with its intruded granite, may represent another synclinally disposed portion or portions of the Garhwal *nappe*. The Garhwal *nappes* have not yet been worked out in detail but they comprise phyllites which may be the equivalents of the Chails.

In the southern scarp of the main range of Garhwal, Auden records a thrust-plane separating below, para-gneisses and schists which may belong to the Jutogh series of the Simla area, and above, rocks of the metamorphosed Chandpur series which are probably the roots of the Garhwal *nappe*.

Some of the granites of the granite zone are sheared and crushed and appear to have intruded either before or during the thrusting movement. The granite intruded into the Chandpurs forms part of the Garhwal *nappe* and has been thrust along with the parent rocks. The relation of the granites to the Tethys zone is at present obscure.

In eastern Nepal and the Darjeeling area three thrust-planes have up to the present been recognised. One of them, which cannot be older than Pleistocene, separates the Nahan from the underlying Upper Siwalik conglomerates.[50] That between the Gondwana rocks and the subjacent Nahans is probably the Krol Thrust ("Main Boundary Fault"), while the plane separating the Daling beds from the underlying Gondwanas is conjectured to be one of the Garhwal thrusts.[51] Some open folding or large scale warping is characteristic of the country northeast and southwest of Katmandu.[52] Complex folding is seen in the rocks of north Sikkim, and in the northeastern parts of the State the general strike is N.W.—S.E. instead of the expected E.-W.

In the Darjeeling section of the Himalaya, Arnold Heim and A. Gansser have shown good reason for the conclusion that the order of succession from the plains into the heart of the hills—from the Damuda beds through the Daling series to the Darjeeling Gneiss—is a reversed one. The Darjeeling Gneiss, exposed around Darjeeling

[50] Auden, Rec. 69, pt. 2, 146 (1935).
[51] Auden, Rec. 71, pt. 4, 432 (1937).
[52] Rec. 69, pt. 2 figure 1, p. 142 (1935).

and in the Kinchinjunga *massif*, is regarded as the oldest rock present and the core of an enormous recumbent anticline thrust southwards over a visible surface of more than 80 kilometres.[53] To this fold also belongs Mount Everest which, however, forms part of the upper limb of the anticline and includes none of the core of Darjeeling Gneiss; the summit of this mountain, therefore, with its Permian rocks, does not correspond to the gneissic summit of Kinchinjunga but to the Jongsong peak to the north thereof. As Heim and Gansser remark, it seems fitting that two of the highest mountains in the world should occupy portions of perhaps the largest thrust-fold known. As already explained, the Darjeeling appears to be nothing more than the granite-soaked basal portion of the Dalings, the result of the intimate injection of a granite magma into Daling-like clay-slates.

The two Swiss authorities quoted in the last paragraph have figured an interesting example of back-folding (rückfaltung) in the upper Kali, below Kalapani,[54] where an anticline is seen overlying towards the *northeast,* and not towards the southwest which is almost invariably the direction of Himalaya overfolds.

To what extent thrusting on a large scale is present to the north of the Great Himalayan range is not known; it is at least not entirely absent. Fifteen miles north of Lake Manasarowar, and therefore, some sixty-five miles north of the Great Himalaya, a large thrust has been observed by Heim and Gansser, while the *klippen* described in the next paragraph have been known for a long time.

Exotic blocks in the Tibetan zone.—The detached *blocs exotiques* of limestone and other rocks found in Malla Johar in the extreme north Kumaon and across the Tibetan frontier in Ngari Khorsum, are *klippen* similar to those found in the Alpine and Carpathian Cretaceous Flysch. The culminating ridge of the Zanskar range and its northern slopes in this region consist chiefly of Spiti Shales overlain by Giumal Sandstone, passing up into a sandstone and shale series which is of Cretaceous age and resembles very closely the European Flysch. These Mesozoic beds are synclinally folded. Resting sometimes on the Spiti Shales and sometimes on the Flysch, and inextricably associated with and embedded in masses of andesite and other basic volcanic rocks of Cretaceous or Tertiary age, are these innumerable blocks of sedimentary rock of all sizes from that of mere pebbles to masses of many cubic yards.[55] Scattered among the volcanics and sedimentaries, with no trace of regularity or arrangement, these blocks, composed of limestone, sandstone, Spiti Shale and Flysch, belong to every stratigraphical horizon from Permian to Upper Cretaceous. In most cases the blocks are unfossiliferous, but many of them have yielded recognisable faunas which have already been described. Those of Lower Trias and Anisian age show a

[53] Denkschr. d. Schweiz. Naturf. Gesellsch., Bd. 73, Abh. 1, 13 (1939).

[54] *Ibid*, figure 67.

[55] Burrard & Hayden "A Sketch of the Geography & Geology of the Himalaya Mountains and Tibet", 238 (1907).

close faunistic affinity with the corresponding beds *in situ* in Spiti and Kumaon, but exhibit lithological differences. In blocks of Carnic age, however, the rocks of the *klippen* differ in their fauna as well as in their lithology from the Spiti-Kumaon facies; incidentally they strongly resemble the Mediterranean beds of the same age.

The total area over which these foreign blocks are to be found is not known, but they have been recorded as far south as Kungribingri in Almora, and eastwards beyond the Chaldu river; recently they have been found by Gansser as far east as the Amlang La. a pass southwest of Lake Rakas (Lagang) and near its western shore.[56] Northwards they include the peaks of Ghatamemin and Sami; they have been noted several miles north of Balchdhura No. 2 and also to the north of the Niti Pass.[57] In most cases these *klippen* are arranged in rows, the longest of which contains the blocks of maximum size. One of these lines, curving sinuously along the Kiogarh ridge, is approximately parallel to the strike of the enclosing rocks, and others may be the same. In the Chitichun area there is a much shorter line, slightly curved and having a general direction more or less at right angles to that of the Kiogarh line. The blocks were at one time thought to have floated to their present position on floods of lava. There seems little doubt, however, that the suggestion, made in the first case by Griesbach, that they are detached rock masses brought into their present abnormal situation by faulting, is true, provided that by faulting we understand thrust-faulting of an appreciable magnitude. The roots of these *klippen* may eventually be found on the northern slopes of the Kailas range further north. Heim and Gansser describe the Kiogarh blocks as the remains of a thrust-sheet which has travelled a long distance from Tibet, and part of a sedimentary series of great extent and more or less broken up by basic intrusions.

Metamorphism.—One of the most important facts emerging from work in the Himalaya is that the degree of metamorphism, cleavage and crushing is not merely a factor of time but is due mainly to stress and locally to igneous intrusion. Although the degree of alteration shown by immediately neighbouring rocks, especially in sections transverse to the general strike, is sometimes a useful clue to their relative age, there is no regular increase in metamorphism with age, and most of the geological formations exhibit varied degrees of change which can be traced along the strike of the beds concerned. In the Krol Belt, from the Simla Slates (? pre-Cambrian) to the Nahans (Miocene) Auden finds it impossible to differentiate the rocks merely by their metamorphic condition.[58] He finds, for example, that in the Simla Slates as well as in the Tertiary Kasaulies, soft green needle shales occur interbedded with clay-slate. "In the Jaunsars occur sandstones, quartzites and quartz schists in close association. Single beds of quartzite may be marked out by extreme permeation

[56] Denkschr. d. Schweiz. Naturf. Gesellsch. Bd. 73, Abh. 1, 174 (1939)

[57] Kraft, Mem. 32, p. 3, 131 (1902); Rec. 37, pt. 1, 24 (1908).

[58] Rec. 67, pt. 4, 408 (1934).

with vein-quartz due to crushing, while adjacent beds are free from veining. Clay-slates, slates, phyllites and chlorite schists, all occur close together, the green beds being especially susceptible to alteration. In the Blaini, marmorised Krol limestone may be seen to lie on unaltered red shales which have been penetrated by sheared dolerites. In the Subathus may be found graduation from soft purple and green shales to hard, tough, phyllitic clay-slates, penetrated with veins of quartz." Within the tectonic "windows" of Garhwal, the Subathu (Eocene-Oligocene) shales have become so highly sheared, as the result of the Miocene thrust movement, that they have developed abundant reflecting slip surfaces and have the appearance of a biotite schist.[59] In many parts of the Lesser Himalaya, metamorphism has not obliterated structures like current-bedding and ripple-marking even in rocks of ancient formations.

While the Peninsular region can show ancient rock systems like the Vindhyan with practically unaltered sediments, the Krol Belt of the Himalaya, between Subathu and Kalsi, composed for the most part of much younger rocks, is characterised by typical epi-conditions of metamorphism. In the case of the limestones it is clear that the stress has acted without the influence of any considerable temperature. The schist belt adjoining the Krol Belt to the northeast contains rocks showing epi- and meso- conditions of metamorphism, while the Tertiaries to the southwest are generally unmetamorphosed but are locally indistinguishable from *epi*-type rocks of the Krol Belt; there is, however, no absolute division, and *epi*-type metamorphism is seen in all three zones. As Auden remarks, that the pre-Tertiary and Tertiary rocks show the same degree of folding is an indication, not that the earlier rocks have escaped previous folding, but that the later Himalayan movements were as intense as any that had preceded. It was more than simple erosion of more or less horizontal structures that the pre-Tertiary rocks had undergone previous to the deposition of the Tertiaries. In the tectonic equivalent of the Krol Belt in Garhwal, there is an increase in metamorphism from southwest to northeast, the Chandpurs of this *nappe* within a distance of ten miles changing from banded green slates and ash-beds to schistose chlorite-sericite phyllites, and the soft sandstones and quartzites with a secondary silica cement of the Nagthats becoming schistose chlorite-sericite quartzites.

The variation in the degree of metamorphism exhibited by the Himalayan sediments is well exemplified in the Chaur area, where the recrystallised quartizites, quartz schists and phyllites of the so-called Chail series have been brought from the northeast by a thrust to rest on slates which show a distinctly lower grade of metamorphism and were, therefore, named the Simla Slates; it is now believed that the two sets of beds belong to one and the same formation, and that the Simla Slates represent but the middle and upper portions of the Chails.

There is an increase in regional metamorphism from the central parts of the Kashmir synclinoriam described on page 2036 north-east-

[59]Auden, Rec. 71, pt. 4, 419 (1937).

wards towards the heart of the mountain chain. Along the north-east side of the basin the grade of metamorphism is low or moderate, the most prominent features being the cleavage and phyllitisation of the slates, and the chloritisation and epidotisation of the volcanic rocks. In the more central portion of the Great Himalaya in Kashmir the uralitisation of the basic rocks and the granulitisation of the acid gneisses and schists are common changes, and minerals such as uralite, actinolite, garnet, staurolite, kyanite and sillimanite make their appearance. In this central zone the detached outcrops of Cretaceous as well as Trias have been recrystallised and in few cases rendered schistose, though fossil structures still remain visible. Speaking of this part of the Himalaya, Wadia remarks that metamorphism, tectonic deformation and igneous intrusion are closely correlated phenomena and reach a maximum of intensity in the broad mountainous belt on the north side of the Kishenganga, the Nanga Parbat region exhibiting signs of extreme stress.

On the north flank of Everest, those sediments of the Tibetan zone which are close to the main range have been metamorphosed to crystalline limestones, actinolite schists and epidote schists. They have a dip to the north and pass up into the unmetamorphosed Jurassic beds of the ordinary Tibetan zone facies.

Auden has found that, in the case of pelitic sediments, the less metamorphosed forms of phyllite and slate appear to be the result of the general regional stresses operative at the time of the impress, while the more intense alteration to schist is always related to intrusions of granite.[60] Wadia concludes that by far the larger part of the schist zone of Hazara and Karnah consists of regionally as well as thermally altered Dogra (Hazara) Slates. These slates with their ubiquitous dolerite dykes and rare thin limestones have been permeated with the granite now known as the Central Gneiss, and by it converted into phyllites, hornfels and thinly foliated garnetiferous biotite schists with occasional staurolite.[61] In the Dudatoli area, again Middlemiss found that the rocks near the granite are true crystalline schists but grade outwards into less altered forms which ultimately assume the form of slates and quartzites.[62] In the Sutlej and Spiti valleys, the Haimanta Slates (Cambrian) have been altered by granite intrusions to staurolite schists, kyanite schists and garnetiferous mica schists.[63] Similarly, in the flanks of Mount Everest the Triassic and Jurassic shales and limestones have been metamorphosed by the permeation of tourmaline granite to mica schists and calc-silicate rocks.[64] In the last mentioned example the intrusion is of Tertiary age ; in the other three cases cited in this paragraph the instrusion dates probably from the end of the Palaeozoic era.

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[60] Rec. 67, pt. 4, 413 (1934).

[61] Rec. 65, pt. 2, 201 (1931).

[62] Rec. 20, pt. 3, 137 (1887).

[63] Hadyen, Mem. 36, pt. 1, 9 (1904).

[64] Rec. 54, pt. 2, 223 (1922).

An attempt has been made by Auden to disentangle the various stages of metamorphism which have affected the rocks of the Lesser Himalaya, more especially those of the Krol Belt, and this paragraph is for the most part a summary of his interesting conclusions.[65] The factors to be considered are four in number: (i) the possible existence of Archaean schists of *meso*-type ; (ii) the broad regional pre-Tertiary metamorphism of the Palaeozoic sediments ; (iii) metamorphism due to Tertiary orogenic movement ; and (iv) the changes effected by granite intrusions whether of Palaeozoic or of Tertiary age. The pre-Tertiary regional metamorphism of the Palaeozoic sediments appears to have been of *epi*-type. The later impress, resulting from the Tertiary orogenic compression was also of the same type. The superposition of this later *epi*-grade metamorphism on an earlier metamorphism of the same type has, in the words of Auden, had no additive effect. It is only where we find granite intrusions, whether of Palaeozoic or Tertiary age, that we encounter changes of *meso*-type. The Krol Belt, for example, which has been affected by no granite intrusions, is without *meso*-grade rocks. This being so, we should expect the pre-Tertiary conglomerates, so common throughout the sequence in the Krol Belt, to yield fragments of any rocks of *meso*- or higher grade, *if* such rocks were exposed to denudation at the surface during the accumulation of the sediments which now make up the Krol Belt. " It is a striking fact that, except in one rock-slice of the Blaini boulder bed, no single instance has been found either in the field, or in rock-slice, of any true schists or metamorphic rocks of *meso*-type being included in the pre-Tertiary conglomerates. Phyllites, black (? carbonaceous) slates, and sandstones are found abundantly as fragments in the Simla Slates, the Morar-Chakrata beds (largely Simla Slates) and the Blaini ; but never schists, never garnets, and only one case of a completely recrystallised mosaic-quartzite. The boulders in the Blaini are almost entirely dark slates, sandstones and quartzites, all types which can be matched in the Simla Slates and Jaunsars. The boulders in the Jaunsars are mostly of material derived from penecontemporaneous erosion, while the abundant pebbles of vein-quartz perhaps indicate a granite-pegmatite source. In the Jaunsar arkoses are found plagioclase felspar and tourmaline. In the Tal arkoses occur microcline and tourmaline. The provenance of these minerals was almost certainly granitic. Aside from these indications of the existence of graintes. there is extremely scanty indication of any derivative environment to the whole sequence of rocks in the Krol Belt other than that showing *epi*-metamorphism. Not until the Dagshais, of Oligocene or Miocene age, are there found metamorphic rocks and minerals of *meso*-type. In the Dagshais and Kasaulis, garnet is abundant. In the Sutlej rocks, garnet and pebbles of recrystallised quartz schist may be found ".

Of any metamorphism older than that which affected the Palaeozoic rocks before the Tertiary era, the evidence is negative in character and also somewhat anomalous. The Salkhala and Jutogh beds

[65] Rec, 67, pt. 4, 415 (1934).

of Kashmir and Simla, respectively, were at first provisionally assigned to the Archaean, but their *meso*-type of metamorphism may be due to the intrusion of Carboniferous granite as much as to any previous alteration of Archaean age. As Auden points out, the absence of pebbles and boulders of schist or metamorphic quartzites from ancient pre-Carboniferous formations such as the Simla Slates and Jaunsars, would seem to indicate either that no area of metamorphic rocks of *meso*-type was exposed to denudation at the time of deposition of these sediments, or that metamorphism of *meso*-type had not then affected any of the neighbouring rocks. If gneissic granite is found as pebbles, it might be expected that schist would also occur as such ; even if the absence of schist pebbles be attributable to their readier disintegration, we should expect to find index minerals such as garnet among the sedimentary detritus.[66] The absence of such pebbles or mineral fragments might be due to the fact that before the Tertiary thrusting, Archaean schists did not happen to be in the vicinity of the area of deposition of the Simla Slates and Jaunsars so far known to us ; this seems unlikely. An alternative view is that, during the accumulation of the Simla Slates and Jaunsars, the Salkhalas and Jutoghs existed in the form of phyllites rather than as schists ; this also seems improbable since there are convincing grounds for believing that the Archaean rocks of the Gondwana continent—certainly of the Indian Peninsular portion thereof—had become schistose long before the Purana era. So far as evidence is available, therefore, we seem driven to the conclusion that Salkhalas and Jutoghs are not of Archaean age but belong to the later Purana era. As Auden remarks, Archaeans must have formed a basement and margin to the area of deposition of the Simla Slates, but they have left no recognisable traces of the characters they now elsewhere exhibit.

Oblique orientations.—Brief allusion has been made in a former chapter to certain strikes, structures and deformations which are abnormal in that their orientation, instead of being N.W.-S.E., parallel to the Himalayan axis, is more or less at right angles, *i.e.*, approximately N.E.-S.W. These features have been noted between Chakrata and Naini Tal, a tract of the Himalaya which is in a line with the Aravalli range, across the Indo-Gangetic alluvium, and it has been suggested that they are relics of the movement which produced the Aravalli folding and upheaval. As early as 1890 Middlemiss recorded the presence of structures in Kumaon oblique to the axis of the Himalaya and displayed in basic volcanic rocks with interbedded quartzites and slates ; of pre-Tertiary age these rocks show folding, cleavage and crushing along a N.-S strike.[67] Recently a number of observations made by Auden have shown that phenocrysts, as well as lenticular and linear structures in the gneissic granite of Lansdowne, sometimes have an orientation averaging N.E.-S. W. Similar anomalous directions have been noted by the same

[66] Rec. 67, pt. 4, 418 (1934).

[67] Mem. 24, pt. 2, 125 (1890).

authority in the tectonic elongation of pebbles in the Jaunsar conglomerate along the Palor river, in the folded ripples of phyllites of the same series at Shallai, in the schistosity of Jaunsar quartz schists near Andra, in the elongation of the boulders of the schistose Blaini boulder bed on the ridge between the Juin and Chandpur summits, and, lastly, in andalusite idioblasts in a hornfels near the Ramganga river. The hornfels of the last example is a product of metamorphism of the Dudatoli granite, which is almost certainly the equivalent of the Lansdowne granite. The age of this granite intrusion, as we have seen, is in all probability either Carboniferous or older, while the Jaunsar series is assigned provisionally to the Devonian. In beds younger than the Blaini, such as the Infra-Krol and Krol, no orientations along Aravalli directions have been observed by Auden. Accepting the Blaini as Upper Carboniferous, it follows that these anomalous orientations cannot be dated later than Carboniferous[68] It is true that the border folds of the southeast flank of the Aravalli range tend to splay out at their northeastern extremities and to assume a N.W.-S.E. strike, *i.e.*, parallel to the Himalaya, but no such tendency is seen in the folds along the northwestern flank of the range. After making allowances for change of strike due to the greater relative advance of certain portions of a *nappe* as compared with other portions,[69] there is reason to suspect that the features described are relics of a late phase of the Aravalli folding which have escaped obliteration by the later Himalayan plication; if so, this phase seems to have ceased in Blaini or Upper Carboniferous times.[70] It is only right to add, however, that the anomalous orientations mentioned above are not common and are greatly outnumbered by normal or haphazard directions in the Himalaya opposite the Aravalli.

Abnormally directed ridges.—Throughout a mountain belt as wide as the Himalaya, many transverse or oblique ridges arise as the accidental result of localised erosion, but there are three examples which, by reason of their unusual length and importance, are worthy of special notice. One of these is the Narkanda-Mahasu ridge which, from the high snows east of Simla runs diagonally across the rest of the Himalayan flank westwards to the low plains. So prominent a feature is this so-called ridge, which forms the southern boundary of the Sutlej basin, that it was regarded by more than one early observer as the termination of the Himalayan chain. Since it cuts obliquely across the strike of the rocks, it cannot be looked upon as anything more than an erosional feature—the watershed between the drainage into the Arabian Sea on the one side and that into the Bay of Bengal on the other. The well known "Ridge" in Simla is situated on this watershed and while a pebble dropped on one side

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[68] Auden, Rec. 66, pt. 4, 468 (1933).

[69] Some of the transverse strikes in Garhwal are said to be accompanied by mylonisation and may, therefore, be deflections due to thrusting. Mem. 24, 178 (1890).

[70] Auden, Rec. 67, pt. 4, 449 (1934).

of the Church might find its way ultimately to the Arabian Sea. another dropped on the other side might eventually be added to the Ganges delta at the head of the Bay of Bengal. Such a watershed was bound to arise somewhere since the Ganges and Indus basins became separate and individual drainage areas. It is true that the uniformity of descent in this line of high relief is almost unbroken, but the line itself winds irregularly across the country and scarcely deserves the name of ridge. Separating the basins of the Sutlej and Jumna, it is parallel to the oblique direction of the drainage of the westernmost section of the Himalaya, corresponding to the oblique orientation of the Lesser Himalayan ranges here to the main range. The oblique direction and symmetry of the basins of the Punjab rivers, such as the Sutlej, Beas, Ravi, Chenab and Jhelum, are in noticeable contrast with the more closely transverse symmetrical basins of the rivers further east, such as the Tista, Kosi, Gandak and Karnali.

The other two examples, which form the western and eastern boundaries of Sikkim, are more remarkable and less easy of explanation. These are the N-S. Singalila and Chola ridges, extending to the plains, the former from Kinchinjunga and the latter from the Pauhunri peak. Both ridges are practically at right angles to the general direction of the Himalaya, which would here be almost due E.-W. were it not for an arching of the main range towards the north between Kinchinjunga and Pauhunri. In the main there can be no doubt that these ridges are erosional features, formed by the cutting back of the Tista. This river occupies a basin which is exposed to the full force of the southwest monsoon as it sweeps unchecked through the gap between the Rajmahal and the Garo hills. The rainfall in the Darjeeling district and Sikkim is, therefore, unusually high; in the hill-station of Darjeeling the annual fall is some 120 inches as compared with 90 inches at Naini Tal or 80 inches at Simla, both of which stations have approximately the same altitude of about 7,000 feet. The Tista has in consequence carved an enormous bowl-shaped basin, the western and eastern boundaries of which are the two ridges under consideration. In doing this it has been assisted by its success in having carved its way down through the overfolded gneiss into the more easily denuded slates, phyllites and mica schists which happen to lie beneath. At the same time, the northward curving of the great range between Kinchinjunga and Pauhunri appears to be due to some extent to a change in strike, and not exclusively to the cutting back of the Tista and its tributaries beyond the crest line. The general strike in northeast Sikkim was found by Auden to be N.W.-S.E., changing probably to an E.-W. direction further west. It has been suggested that anomalies of this kind are conceivably the effects of an easterly pressure from the direction of Burma along the range.[71] Wager has expressed the opinion that the deviation from the normal Himalayan orientation may be evidence of an older

[71] Burrard & Hayden, "A sketch of the Geography and Geology of the Himalaya Mountains and Tibet," 77 (1907).

mountain chain trending in a different direction.[72] Much work remains to be done in this little known region.[73]

Age of the Himalaya.—The age of the Himalaya, either as a simple tectonic feature or as a complex mountain range, is a question on which much has been written and which must now receive attention. In the first place certain *a priori* considerations present themselves. All the early earth movements which affected India had a general E.-W. or N.W.-S.E. direction; locally there were considerable variations from these orientations but the predominant "grain" of the Indian peninsula averages about N.N.E.-S.S.W. The most important of these movements, so far as the modern configuration of India is concerned, was that which built up the Aravalli range in Rajputana, and was in all probability comparable in intensity, duration and effect with the Himalaya. It was not till the early part of the Gondwana era that any disturbing force acting along a N.E.-S.W. direction affected the country. Part of this stress, which is believed to have accompanied the deposition of the Gondwana sediments, seems to have been tensional, but there is evidence to show that some of it at least was compressional as early as the Karharbari epoch, *i.e.*, in early Permian times. Whether we assume that this compression initiated the Himalaya along some axis in the Tethys geosyncline depends, among other things, upon our conception of the nature and breadth of this feature. If we accept the theory of inter-continental drift, we must suppose the Indian portion of Gondwanaland to have lain at that time in considerably higher latitudes to the south, and to have occupied a considerably larger area since its northern margin had not yet been reduced by folding and underthrusting. The southwardly folding Himalayan margin of the Gondwana landmass and the northwardly folding Kuen Lun margin of the Angara continent formed what De Terra has called a frame for the geosyncline which lay in between, [74] and was occupied by a sea which would have narrowed and shallowed as the two continents approached each other. The early N.E.-S.W. compression in the Damuda valley Gondwana basins rests upon limited though distinct evidence, but does not seem to have attained intensity. The further movement which affected the Gondwana basins and was more or less responsible for their preservation, is not easy to date with certainty. Some of the compressional stress may even have been as late as Tertiary, but

[72] Ruttledge, "Everest 1933", 320-321 (1934).

[73] According to M. Argand, "on a cru reconnaitre, dans diverses chaines, des plis transversaux plus or moins intenses. Mais la genese de plis transversaux, dans une chaine reglee, est mecaniquement inconcevable hors un cas recemment mis en evidence : celui ou un arc d'une certaine largeur est contraint a accentuer la courbure de son plan : le cote externe, travaillant a l-extension, s'etire pendant que le cote interne, siege d'unc compression longitudinale, peut preudre des plis transversaux de detail qui sont, comme on voit, lies a la mise en place de l'objet principal et ne forment pas un episode independant." (C. R. Congr. geol. internat., 13th Session (1922), p. 177). No definite local accentuation in the curvature of the Himalayan arc has been so far recognised either in the Kinchinjunga section or elsewhere.

[74] Rep. Internat. Geol. Congr. Wash. Vol. 2, 863 (1933).

the bulk of the movement and especially that portion of it which caused the vertical displacement of the Gondwana sediments, is believed to have taken place towards the end of the Gondwana era, *i.e.*, at the end of the Jurassic or beginning of the Crataceous period. If the compressional element of this disturbance is rightly referred to the Gondwana era and not entirely to the Tertiary, and if it contributed towards the upheaval of the Himalayan chain, it must have been interrupted by the Deccan Trap period, unless it were possible for tension in the Indian Peninsular region to occur simultaneously with compression in the region now known as the Himalaya.

In speaking of the formation of the Himalaya, it is necessary to distinguish between the comparatively gentle uplift from the Tethys sea which must have initiated it as a landmass, and that later compression which caused it to rise up as a conspicuous mountain range with much the same limits and extent as at present and involving the northern margin of the Gondwana continent. The movement which first marked out a terrestrial belt along the Himalayan area may have begun in Cretaceous times, but such pre-Tertiary movement seems to have been one of gentle uplift and there is no evidence of mountain building before the middle of the Tertiary era.

The formation of the Himalaya as a mountain chain belongs to the movement which produced the Alps. In the Himalaya, thrusting and overfolding were always to the south, omitting purely minor and local exceptions, at the same time northwardly directed folds and thrusts are seen in the Kuen Lun which forms the northern edge of the Tibetan plateau. In the language of the Continental Drift theory, the Indian landmass was thrust under the sediments off the Angara coast, a condition of things which is conventionally and conveniently referred to as an earth movement from the north, *i.e., from* the over-riding to the over-ridden region. As already shown, relics of the infolded edge of this Indian landmass have been recognised in the Himalaya.

On the supposition that the marginal sediments of a northern landmass were invaded by a southern landmass, some fundamental differences in the fauna and flora of the two regions might be expected. Such a comparison, however, is highly complicated by the fact that the climatic and physiological conditions in the two regions are so entirely different and so completely and effectively separated by the enormous obstacle of the Himalaya. These factors alone would account for marked differences and no surprise can be felt at finding that many members of the trans-Himalayan fauna of today show closer affinity with central Asian forms than with species found south of the mountain chain. It was long ago recognised that the modern fresh-water life of eastern Ladakh, for example, is related to central Asian rather than to Indian forms.[75] F. Day in 1878 noted the marked difference in the fish faunas of central Asia and India and

[75] De Terra, Geogr. Rev. 24, No. 1, 13 (1934); See also G. E. Hutchinson "Nature", Vol. 132, pt. 136 (1933).

seems to have attributed it to the insuperable barrier of the Himalaya. In 1909 F. H. Stewart, referring to the eastern half of the Himalaya, found that of the Siluridae and Cyprinidae, two families of fresh-water fish, fifteen species are confined to the northern region, thirty-four to the southern, while two only are found in both.[76] To deduce that these northern and southern fish faunas have a fundamentally different ancestry is not, however, permissible; S. L. Hora, in fact, from a recent study of Indian fish, concludes that both the cis-Himalayan and trans-Himalayan fish are the result of migration north-westwards from Further India much of which was originally part of the Angara landmass.[77]

The northern fringe of Gondwanaland now lies under the Tibetan plateau, a portion of it having become folded up with the crumpled marine sediments of the Tethys sea. In M. Argand's sketch section, the two *blocs continentaux* (Gondwanaland and Angaraland) are shown as overlapping each other beneath the Tibetan sediments, the most forward element of Gondwanaland extending as far north as a line vertically beneath the Kuen Lun scarp, and the Angara front as far south as the middle of Tibet.[78] The corrugation and upheaval of the Tethys sediments were the concomitant results of the mutual approach of the two continents. Where it lay, the north coast of the southern continent must have been traversed by northwardly-flowing rivers—continuations of rivers like the Son and Chambal now draining the northern parts of the Peninsula.

The distribution and nature of the Siwalik conglomerate provide some indications as to the age of the Himalayan chain. There is a remarkable resemblance between the Upper Siwaliks and the sub-montane deposits of the present day. Not only are the Upper Siwaliks so similar in general character to the recent deposits that they have been aptly compared to an elevated portion of the plains, but there is precisely the same variation in composition according to their position with reference to existent lines of drainage. Opposite the debouchures of the main rivers draining the central portions of the Himalaya, the present-day gravel slopes or *bhabar* reach a great development and are composed almost entirely of boulders of hard crystalline and metamorphic rocks which have most of them been well rounded in their long journey down the river valleys. Boulders of limestone are somewhat rare, while the softer varieties of slate and sandstone are almost absent, having been unable to withstand the severe handling of the torrents. In the stretches intermediate between these debouchures of the great rivers, the nature of the gravel varies according to the rocks exposed within the catchment areas of the streams; except in the case of streams draining only the outer hills of Siwalik conglomerate, this gravel is found to in-

[76] F. H. Stewart, Rec. Mus., III, pt. 2, 121-123 (1909); F. Day. "Scientific Results of the Second Yarkand Mission"—Ichthyology, 1-25, Calcutta. (1878).

[77] "Current Science", VII, 351 (1937); Rec. Ind. Mus., 39, pt. 3, 241 (1937); *Ibid.*, p. 251 (1937); Proc. Nat. Inst. Sci. Ind., Vol. 4, No. 4, 395 (1938), "Current Science", Vol. 6, No. 4, 494 (1938).

[78] C. R. Congr. Geol. Internat., 13th Session (1922), Fig. 13, p. 349.

clude fragments of limestone, sandstone or slate, which are often sub-angular, owing to the shorter distance they have travelled and are always less rounded than the hard boulders of the great rivers. If we now examine the Tertiary or Pleistocene equivalents, we find in the Sub-Himalaya of Kumaon a great development of the Upper and Middle Siwaliks, especially of the Boulder Conglomerate, where the Kosi and Ramganga rivers issue from the hills. To the west, where there are no large streams draining from the interior of the hills, the whole Siwalik zone becomes constricted and the Nahan group alone is seen. Further on, from the Ganges to the neighbouring Jumna, the Upper Siwalik conglomerates again attain a great thickness and are composed of well rounded boulders of hard rocks, precisely similar to the debris brought down by these rivers at the present day. At the Jumna the conglomerate beds are not much more than 2,000 feet thick and westwards they almost die out for the time being, those seen consisting of fragments, many of them sub-angular, of the older Tertiary sandstones and of other formations found in the outer part of the Himalaya of this region. Further on, where the Sutlej issues from the hills, there are perhaps 3,000 feet of brown sandy clays.[79] The same features have been noticed in the case of all the other great rivers ; in their neighbourhood the Upper Siwalik conglomerates attain a great thickness and are composed of water-worn boulders of hard rocks, while in the intermediate country they are generally represented by brown clays indistinguishable from the recent alluvium or, if conglomeratic, contain pebbles of local debris.

There is but one possible explanation of these resemblances, *viz.*, that the Himalayan chain already existed when the Upper Siwaliks were being deposited, with very much the same boundaries as at present, with the principal features of its drainage already established, and with an elevation comparable to that of the present day. As examples, two of the rivers which brought down the boulders now found in the Siwalik Boulder Conglomerate were the direct ancestors of our modern Sutlej and Ganges. The presence of so much mica, of magnetite and occasionally of felspar fragments, in the Upper Siwaliks, shows their origin to have been crystalline schists or granitic rocks, while the freshness of the material proves that it cannot have travelled far ; such indications point to the Himalaya as the source of the sediments.[80] The Siwaliks now form low hills in which these once horizontal deposits have been disturbed, elevated, and exposed to denudation, all of which facts point to a southerly advance of the margin of the hills since the Upper Siwalik epoch.

The whole of the Siwalik deposits were accumulated sub-aerially and, even now, after the elevation they have undergone, attain a height above sea-level which, at its maximum, is only about a third of their total thickness. They can only have been formed in a gradually subsiding area, and we may conclude that the plain country south of the hills, where conditions are so similar to those under

[79] Rec. 9, pt. 2, 57 (1976).

[80] Middlemiss, Mem. 24, pt. 2, 112 (1890).

which the Upper Siwaliks were formed, and where immense masses of debris have been heaped up without raising its level—much above the alluvial plain to the south, is an area along which a great subsidence has taken place, much of it during the Recent period. The Indo-Gangetic depression is, in fact, a foredeep between the wave-front of the Himalayan system of folding and the horst of Gondwanaland, now represented in part by the Indian peninsula.

In a general way the Tertiary beds show signs of less compression as they recede from the hills. In a general way also there is a decrease in coarseness of sediment away from the mountains and, so far as our very limited knowledge of the subterranean portions of the Indo-Gangetic alluvium goes, this statement applies equally to this alluvium ; when a stream issues from the rock area of the hills on to the alluvial plain, it is naturally the coarsest debris which is first deposited, while the finer material is carried further afield and deposited at a greater distance from the hills.

Wherever the Siwalik zone attains any considerable width, it is found to be traversed by one or more reversed faults—the so-called "Boundary Faults" already alluded to—running more or less parallel to both the outer and inner boundaries of the Siwalik outcrop. These faults not only show an ascending section on the outer or southern side as described, but, the dip on this side usually flattens towards the fault, where the uppermost beds are seen in faulted contact with strata of a much lower stage. Moreover, immediately north of the fault, the older beds are almost invariably thrown into an anticline, the southern limb of which is occasionally cut out but, when present, shows an increasing dip as the fault is neared.

There are no sections showing the nature of the junction between the undisturbed Recent deposits of the plains and the upraised Siwaliks, but the structure and sequence have features in common with those just described as occurring within the Siwalik outcrop itself, and there is little doubt that the plane of contact is here also a reversed fault. The steady sweep of the boundary along the length of the Himalaya, and the absence of any deep re-entrant angles or outlying patches, show that it is in the main a structural feature and that only its details have been affected by denudation and sedimentation. Nowhere along this line are the Upper Siwalik conglomerates found passing conformably beneath the Recent deposits at the foot of the hills, and the outermost ridge of the latter is always an anticline whose southern limb shows an increasing steepness of dip in a southerly direction. The beds actually in contact with the submontane gravels may be uppermost Siwaliks or may belong to the lower part of the Nahan group, while the dip may be moderate, vertical or inverted ; rarely the whole southern half of the anticline may have been eroded away and covered up by Recent deposits but, where it is seen, there is usually a rapid increase in the steepness of the southerly dip near the margin of the hills. These indications of a line of special flexure close to the southern edge of the hills afford some support to the supposition that the contact is a reversed fault. Without being in too strict a sense a boundary of deposition, each

successive reversed fault indicates in a general way a southerly advance, step by step of the outer margin of the hills.

With few exceptions, there is a limitation of marine Mesozoic and Palaeozoic rocks to the northern flank of the main snowy range, marking probably an original limit of deposition. Nevertheless, assuming the southern limit of these marine formations to represent approximately the recurrent shore of a long series of epochs, it is difficult to believe that a mountain range at all comparable with the Himalaya of the present day lay immediately to the south of these deposits. At the very birth of Gondwanaland, which seems to have happened after the folding of the Purana rocks, the line of the Himalaya appears to have been the approximate site of its northern coast but not, previous to the Tertiary era, as a mountain range. The present geographical and geological connection between the Himalayan range and the Tibetan highland is too close to make it at all probable that the elevation of the latter was altogether posterior to, and independent of, that of the former. Consequently, the elevation of the Himalaya as a mountain chain cannot have been long in progress, if it had commenced, when the sea flowed over Tibet at the close of the Mesozoic era.

The complete absence of any known exposure of marine Eocene rocks between western Garhwal and the Garo Hills of Assam might mean only that the shoreline of the Eocene sea ran south of the present limit of the hills, and that Eocene beds are hidden beneath the Gangetic alluvium or under overthrust older rocks. Our knowledge of the Eocene fauna of the Garo Hills and other parts of the Shillong plateau is scanty but, so far as it goes, it does not indicate a relationship between this fauna and the Eocene fauna of the Punjab sufficiently close to necessitate or even suggest a direct sea communication between the two areas. There is consequently some degree of probability that the Indo-Gangetic depression did not exist as a continuous marine gulf along the whole length of the mountain foot in Eocene times. Assuming, as we are justified in doing, that the Indo-Gangetic trough is of the same age as the range, we may conclude that neither feature had attained any great magnitude in the Eocene period.

The stratigraphical relations in the northwestern portion of the Lesser Himalaya between the Eocene beds and the subjacent deposits, point to the same conclusion. There is not only a general parallelism of stratification, which might result from the compression both have been exposed to, but there is a very close resemblance in the nature and degree of disturbance they have undergone, and the Eocene lies with apparently perfect parallelism of bedding on an eroded surface of pre-Tertiary deposits, wherever a section showing the original contact between them is found. From the inliers of the Jammu hills to the outliers east of the Ganges, there apears to have been no appreciable disturbance of the older rocks now forming this part of the Himalaya at the time the Eocene beds were deposited. In other words, if the elevation of the Himalaya had already commenced in Eocene times, it had not extended into the northwest portion, but

was confined to the central part of the chain. We now know that the Eocene sea stretched as far north as the Shali peak and beyond, and to within four miles of Chakrata. In this part of the Himalaya Auden has found these beds resting on formations of very different ages such as Tal beds (Mesozoic), Krol limestones (probably Permian) and Simla slates (pre-Cambrian or Cambrian).

Just as the occurrence of thick beds of coarse conglomerate in the uppermost Siwaliks suggests torrential drainage of a mountainous terrain, so the absence or scarcity of such thick accumulatian of coarse detritus in the rest of the Siwalik succession suggests that the catchment area of the streams was not at that time mountainous, though possibly hilly, and that the gradients of the streams were not steep enough to permit of large pebbles and boulders being transported in any quantity down to the plains below. Throughout the greater part of the Siwalik sequence the coarsest beds which attain any appreciable thickness consist of a comparatively fine sand. It might be objected that a coarse facies of the Lower and Middle Siwalik has been buried beneath the overthrust hills, but there is no evidence of this and the Siwaliks have as yet not been found exposed below any of the Himalayan *nappes*.

An argument of a different character adduced by W. T. Blanford confirms in a general way the conclusions regarding the date of origin of the Himalaya arrived at on purely geological grounds.[81] He points out that the mammalian fauna of Tibet has a proportion of species, and even of genera, peculiar to the region, and that no other continental area of the same size possesses so individualised a fauna. Omitting all doubtful forms, and taking no account of varieties or sub-generic types, the known Tibetan fauna was found to consist of 43 species belonging to 26 genera, and of these, 27 species and 4 genera were not known outside Tibet. Moreover, by far the largest proportion of species ranging outside of Tibet was exhibited by the Carnivora, only 4 out of 9 species of ungulates being known elsewhere: out of 16 species of rodents, only one is not purely Tibetan. So large a proportion of peculiar species indicates a long period of isolation. In the case of island faunas such isolation is the result of the sea barrier which mammals cannot cross or can cross only with difficulty, but in the case of Tibet the isolation must be a climatic one, due to the superior elevation of the region. After comparing the degree of specialisation of the fauna with that of various islands, Blanford came to the conclusion that the isolation of Tibet must have commenced in Middle Tertiary times. This agrees remarkably well with inferences arrived at on purely geological grounds and from a study of the relationship of the Siwalik to the Tertiary faunas of Europe.

The age of the Shali Thrust, northeast of Simla, is post-Dagshai, the absence of Siwalik beds from the Shali "window" being evidence of purely negative value. If the adjacent thrusts are approximately of the same age the *nappe* structure in this part of the

[81] Geol. Mag.; New Series, Dec. III, Vol. IX, No. 4, 164 (1892).

Himalaya at any rate cannot be older than Upper Burdigalian and is much more likely to be later than this, since a period of severe folding must have preceded the *nappes.* The Chail Thrust is partly over Siwalik rocks, and a portion at least of this dislocation must be quite late.[82] Nevertheless, the Sutlej has had time to deepen its gorge through the Shali "window" to the extent of some 10,000 feet since the thrusting took place.[83] Movement along the thrust-planes may have continued interruptedly over a long period, until the warping of the planes prevented any further movement. Most of the thrusts show appreciable warping and some appear to be quite sharply folded. In the Simla and Chakrata area the structure is occasionally complicated by cross faults which were later than the overthrusts, whose traces have been shifted thereby. In Garhwal similar deductions concerning the age of the thrusting are possible. The Krol *nappe* has swept over Dagshai as well as Subathu beds and its formation cannot be older than Burdigalian. It is doubtful whether Dagshais occur beneath the Garhwal thrusts, but Subathu rocks unquestionably do, and these *nappes* may be regarded as certainly younger than the Eocene and possibly not older than the Miocene. The fact that no Siwalik rocks have been found beneath either the Krol of the Garhwal thrusts is again of negative value for, as Auden points out Siwalik deposition may not have extended so far to the northeast. That some of the movement along the Krol Thrust is more recent than Helvetian and may even be as late as Sarmatian, is proved by the frequent juxtaposition of the pre-Tertiary rocks upon the Nahans between the Jumma river and the Darjeeling area. Whatever the date of the earliest movements along the Krol Thrust-plane may have been, the final stages of the displacement could not have been earlier than Middle Pleistocene, as shown by the fact that the Krols at Bilaspur rest at an angle of 35° on Upper Siwalik conglomerates.[84] To quote Auden[85] "in places even the Upper Siwalik conglomerates are involved in overthrust by the pre-Tertiaries. Ten miles northwest of Dehra the boulders of these conglomerates are so shattered that it is impossible to obtain a hand specimen of them. Similar overthrusting occurs at Bilaspur on the Sutlej river. These movements must be of Lower Pleistocene or even of later age. Yet it is difficult to believe that the major horizontal movements of the Krol and Garhwal *Nappes* over a distance of several miles took place as late as this. By Lower Pleistocene times, the rising Himalayan chain must have been dissected to such an extent into blocks by deeply eroding streams that the upper *nappes* had already been worn away into outliers. The formation of these upper *nappes* can only have taken place before erosion had proceeded to such an extent that the outcrops of the *nappes* along an alignment in the direction of movement had been divided off into separate outliers, unable to translate the stresses as a unit. Both the

[82] Rec. 69, pt. 1, 77 (1935).

[83] Rec. 72, pt. 1, 80 (1937).

[84] Rec. 67, pt. 1, 59 (1933).

[85] Rec. 71, pt. 1, 429 (1937).

Krol and Garhwal *Nappes* have been strongly folded, possibly as a result of the resistance offered by the floor upon which the movement was effected. There has since been erosion of these thrusts with the resulting formation of the windows and zig-zag outcrops, and it may be accepted that the major part of the movement along these thrusts took place before river dissection had reached its present pronounced stage. It may, therefore, be assumed that there has been more than one period of movement, the stronger movements occurring perhaps during the Helvetian."

The most marked unconformity in the Tertiary sequence of northwest India is that between the Chharat and the Murree. This is well seen in the Potwar plateau, where the basal Murree, of Lower Burdigalian age, contains nummulites and limestone pebbles derived from the Eocene and overlies the Chharats which have been referred to the Lutetian. Here, therefore the Oligocene appears to be entirely missing. In the Himalaya itself the size of the gap between the top of the Subathu and the base of the Dagshai (Lower Murree) is not known since the precise age of the uppermost Subathu and of the lowest Dagshai has not yet been determined. The Fatehjang stage at the base of the Murrees has not been found in the Himalaya and the Subathus may possibly range up into the Oligocene. The chances are, therefore, that the gap in the Himalayan Lower Tertiary sequence is smaller than it is further west. That some erosion of the Subathu beds took place before the deposition of the Dagshais is made probable by the occurrence in the Dagshai sandstones of fragments of Subathu-like sandstone and possibly other Subathu rocks. This unconformity, however, must have been partly the result of the change from Subathu to Dagshai, which was one from marine or estuarine to fluviatile conditions, a change inevitably accompanied by local exposure and erosion of the old sea or estuary bottom. We must either believe that the Indo-Gangetic trough, as well as the Himalaya, was an area purely of erosion and totally devoid of sedimentation during the greater part of the Oligocene period, or that sediments corresponding to the higher portions of the Oligocene have been hidden beneath the overthrust older rocks, or that the Subathu series includes a large proportion of the Oligocene.

Movement continued during the latter part of the Siwalik period and in post-Siwalik times. Not only has the uppermost Siwalik Boulder Conglomerate been tilted—in some instances to high angles —but its pebbles have in some cases, as for example in eastern Kumaon, been crushed and drawn out by compression.[86] That the Himalayan movement has not yet ceased is indicated especially by the frequent earthquakes which disturb the Himalayan region. The occurrence of marine beds with nummulites at heights of several thousand feet shows that the elevation of these parts of the Himalaya must have taken place since the early part of the Tertiary period. On the Indian side of the great range the highest elevations attained by marine Eocene beds is 11,000 feet; this occurs towards the termination of the range in Kashmir, on the southwestern slopes of the

[86] Middlemiss, Rec. 22, pt. 2, 68 (1889).

Pir Panjal where they are exposed in ridges varying from 8,000 to 11,000 feet above sea-level. The Eocene beds in the Shali "window" above Simla and some distance along the chain, are over 8,000 feet above the sea. On the Tibetan side of the Great Himalaya marine Eocene strata have been recorded at no less an elevation than 18,500 feet in Zanskar; in the Tsipri ridge, north of Everest, and in the Kampa ridge E.N.E. of the same summit, they have been found at heights exceeding 15,000 feet.

Since the end of the Siwalik period, *i.e.*, since the end of the Middle Pleistocene, there has been movement which in places must have attained a considerable magnitude. Remains of animals such as the rhinoceros, antelope, hyaena, horse and large ruminants, typical of comparatively low altitudes but found today in Upper Siwalik strata 16,000 feet above the sea, bear witness to an upheaval of immense proportions since the end of the Pliocene. In the Ramganga valley Middlemiss records a reversed fault which has brought the base of the Nahans practically opposite to the base of the Siwalik Boulder Conglomerate; the throw of this fault measured along its hade works out to 11,880 feet, corresponding to a vertical displacement of 6,380 feet or over a mile.[87] In Hoshiarpur Lahiri has found signs of the Upper Siwaliks having been overthrust on to almost horizontal Older Alluvium of the Indo-Gangetic deposits. In the Nalagarh *dun*, Dagshai beds have been pushed up over the alluvial clays and conglomerates of the *dun*. Near Mastanpura, Dagshai beds are seen resting on thick boulder beds, the junction apparently being a thrust-plane sloping gently towards the plains. These boulder beds, on which a few small isolated *klippen* of Dagshai remain, may belong to the Siwalik Boulder Conglomerate or they may be younger; they cannot at any rate be older than Middle Pleistocene.[88]

Better evidence is yielded by the Pleistocene fauna of the Hundes plain. This fauna includes a rhinoceros and a member of the genus, *Pantholops*, an association which at first sight might seem incompatible since *Pantholops* is a genus peculiar to the Tibetan plateau of today, while a rhinoceros would find difficulty in existing on this plateau, not necessarily on account of the cold, for the Tibetan species may well have been protected by a thick coat of fur, but because of its inability to obtain sufficient sustenance from the scanty vegetation of these arid plains. There would, however, almost certainly have been shallow lakes and swamps when these Pleistocene deposits were being formed, and the river valleys of Tibet could have supported in such circumstances, as they do today, even at a height of over 13,000 feet, a growth of grass and shrubs sufficient for the requirements of the rhinoceros of Hundes. In any case the presence of this animal shows that the climate of Hundes must have been somewhat milder than it now is, and there is little difficulty in supposing that these deposits were raised a few thousand feet without suffering any appreciable tilting. This increased inclemency of climate is partly due to

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[87] Mem. 24, pt. 2, 66 (1890).

[88] Rec. 69, pt. 1, 73 (1935).

the desiccation resulting from a rise in altitude of the Tibetan plains and of the mountains south of them.

There are many indications that the lakes of Tibet have diminished in size—in many cases very considerably—since their formation. Many have been reduced to the salt-covered flats and dry basins so common on the Tibetan plateau. Old beaches, far up on the hill-sides above the water-level or dried lake-bottom, witness to the fact that the lakes once stood several hundred feet higher and covered a larger area than they do today. Old Terraces, some of them 200 feet above the water, are seen, not only above nearly every lake in the great lake basin of Tibet, but along the shores of lakes nearer India. The Pangong lakes on the Ladakh frontier, for instance, exhibit a succession of old beaches which bear witness to a general desiccation, interrupted probably by transient wet periods. Other examples of contraction in volume are seen in the Tso Morari in Rupshu, and in the Kala Tso and Yamdrok Tso, both north of Bhutan. Another result of desiccation is the salinity of the lakes which generally have no superficial outlet; "at the same time it is by no means unusual to find that there is a well-marked channel through the old river gravels which fill the former outlet; . . . the well preserved state of these channels shows that either they have only recently become dry or that they are still in intermittent use." Desiccation may still be in progress but whether this is so or not, there is ample proof that the climate of Tibet was once moister than it is now. There appears to be but one explanation possible of this increased dryness of climate, and that is a rise of the mountains to the south resulting in a more complete interception of the moisture from the southwest monsoon winds.

Paradoxical as it may sound, the profound depth of many of the Himalayan gorges is proof, not only of their immaturity, but of their considerable age, for it is obvious that a long period of time must have been required for their excavation. While in the rivers of the Peninsula erosion has almost ceased except in the uppermost reaches, the rivers throughout the Himalayan region are rapidly abrading along their steeper gradients and are far from having reached their base-level of erosion. One of the characteristic features of the chain is the chasm-like nature of its deep gorges and the precipitousness of so many of its slopes. Innumerable examples of this could be given. A typical one is the gorge leading to the Zoji La a pass on the crest of the main range in Kashmir; this gorge has the aspect of a cañyon, in places a thousand feet deep, with almost vertical sides.[89] The Chenab between Kistwar and Tatri (Thatri) has a typical gorge.[90] The Arun, east of Everest, has two gorges. The upper is a cañyon with almost vertical walls; in the lower the river falls 4,000 feet in 18 miles measured in a straight line and is comparatively straight, with walls rising 5,000 feet and more in uninterrupted slopes too steep for human passage but affording a pre-

[89] De Terra. Mem. Connect. Acad., 8, Art. 2, p. 19 (1935).

[90] See E. Norin, Geogr. Ann., 1926, H., Fig. 10, p. 298.

carious roothold for bushes and trees.[91] The gorge of the Indus below Nanga Parbat is a more stupendous example, the descent from the summit northwards to the Indus bed being a drop, almost in a single stride, of 22,500 feet, in a distance of 14 miles ; [93] the northern aspect of this mountain, however, is described by Wadia as tame compared with the southern face which is made up of naked rock cliffs 12,000 and 15,000 feet high. A model of the Kumaon Himalaya constructed to scale by Major M.O.'C Tandy[92] illustrates graphically the steepness of the contours and the general immaturity of the river system.

The profile of the main river channels shows the same immaturity as the river banks. These valleys all penetrate the hills to within ten miles of the line of highest peaks without rising more than 4,000 or 5,000 feet above sea-level, but as they cross this line there is a sudden rise of the river bed which attains a height of 9,000 or 10,000 feet within a few miles. Above this the gradient falls again and, in the Tibetan region, is not usually more than a few feet per mile of channel. This sudden rise in the river beds as they cross the line of highest peaks is probably due partly no doubt to the greater hardness of the rocks in this particular belt, and partly perhaps to an increased rapidity in the upthrust of the mountain chain. Such marked variation in gradient shows that these large rivers have not yet been able to acquire a more or less permanent profile. These sharp contrasts in the profiles of the Himalayan rivers are not confined to their general aspect but are seen also in the detail of their courses. While the gradient of any particular river bed may be anything from 5 to 20 feet per mile along its longitudinal troughs, the fall across the transverse barrier ranges may be as much as 100 or 200 feet per mile.

There have been recorded two or three cases of relative movement along a fault-plane at so recent a period as to cause interruption of minor drainage courses of today, and to display itself as a visible rise in the surface of the ground—a rise which denudation has not yet had time to obliterate, and which is an indication that earth movement has not ceased.[94]

To recapitulate, though some of the evidence is indefinite, the following conclusions appear permissible: (i) that the line of the Himalaya may have been the locus of gentle initial upheaval in Cretaceous times ; (ii) that there are no signs of any intense compression, capable of building up a mountain chain, until well into the Tertiary era ; (iii) that it had become a barrier of sufficient height and width to isolate the Tibetan plateau by a date estimated to have been the Middle Tertiary ; (iv) that, if this estimate be correct, the slope of the southerly streams, many of which probably rose behind the line of what is now the Great Himalaya, was not steep enough for them to bring down to the plains any abundance of coarse detritus ; (v) that it was not until the Pleistocene period that the slope of the

[91] Heron, Rec. 54, pt. 2, 219 (1922).

[92] Rec. 66, pt. 1, 124 (1932).

[93] See figure, Rec. 43, Pl. 3 (1923).

[94] Oldham, Rec. 21, pt. 4, 158 (1888).

southerly drainage became steep enough to effect the transport of such coarse material, much of which may have travelled during the first stages of its downward journey on glaciers produced by a high altitude; (vi) that the appearance of coarse gravels and boulders in the last Siwalik epoch may be due partly to an advance to lower levels of such glaciers during a colder climate, and partly to an intensification of the compressional movement resulting in a rapid steepening of the southerly slopes; (vii) that the bulk of this late movement took the form of thrusting, large slices of the hills being raised to higher altitudes without suffering any marked additional plication or metamorphism (see next paragraph); (viii) that this thrust movement has not yet ended, and is the cause of the frequent and often severe earthquakes which afflict the Himalaya and its neighbourhood (see page 2102). It was only towards the commencement of the Pliocene that the Himalaya attained an elevation comparable to that it now possesses; its decadence has not yet begun, and the very altitude of the snowy peaks today suggests that their upheaval to their present height must have been quite recent.

Uplift apart from plication.—Signs are not wanting that part of the elevation of the Himalaya is due to uplift unaccompanied by plication. This movement has been referred to as epeirogenic,[95] but is most probably the result of thrusting, for which such a term is scarcely suitable. Several thrusts of considerable magnitude have been described a few pages back, and the effect of the movement of the *nappes* up inclined planes must have been to raise the superincumbent rocks with a minimum amount of tilting or flexuring. Young uplifts of this kind have affected the whole Himalaya and the Karakoram. Movement of any particular plane would no doubt continue until the buckling of the plane itself would obstruct any further progress; another thrust-plane would then be initiated and take over the function of the earlier thrust until it in turn became plicated and functionless.

Palaeontological evidence has already been detailed to show that the Pir Panjal has probably nearly doubled its altitude since the deposition of the Karewah beds without any noticeable buckling or contortion (see p. 1934). Omitting a small monoclinal fold on this range, the dip of the Karewahs of the Kashmir valley does not normally exceed 20° and the greater proportion of the beds diverge very little from the horizontal; the Jhelum, which becomes a raging torrent below Baramula and cuts a gorge through the Pir Panjal, is a navigable waterway in the Kashmir valley above. Dainelli estimates that there has been what he also calls an epeirogenic rise of 8,000 feet in the Pir Panjal since the second half of the Pleistocene;[96] De Terra's estimate of 6,000 feet may be nearer the truth.[97] The practical horizontality of the Ossiferous Beds of Ngari Khorsum also proves that no plicatory movement has affected them since Pleistocene

[95] De Terra, Geogr. Rev., 24, No. 1, 40 (1934).
[96] "Eilippi Ital. Exped. to the Himalaya, Karakoram and E. Turkestan" (1913-1914), Lond., 1932.
[97] Rep. 16th Internat. Geol. Congr., Wash., Vol. 2, 867, 1933.

times, although we have ample grounds for believing that the Himalaya has undergone uplift since that period. The high-level alluvial deposits in the Sutlej and Indus valleys may be of the same age or may be of later date. Such lack of disturbance within the Himalayan mountains or along the Tibetan margin is in significant contrast to the marked tilting—sometimes to a vertical position—which has affected Pleistocene deposits along the foot of the chain.

The phenomenon of rejuvenation seen in most of the important Himalayan rivers today is best understood as being the result of uplift of the highlands among which they rise. The process is well described by Burrard and Hayden.[98] The tendency of a river draining a mountainous region is to remove material from its upper reaches and deposit it in the lower, "thus producing a flattening of its gradient throughout, in consequence of which the depositing section of the stream gradually creeps further and further back towards its head. If, during this process, the land round the head-waters of the stream undergoes a movement of elevation, the gradient and consequently the erosive power of the stream will be increased and the water begin to cut a channel through the deposits which had accumulated in the lower valleys. At the present day the great Himalayan rivers are not depositing in their lower reaches, except near the point at which they debouch from the mountains, and consequently are not in that stage of equilibrium which characterises an old river". On the other hand, their valleys are cut through horizontal deposits of boulders and river gravels, which can be seen to extend three or four hundred feet above the present stream-bed.[99] The river terraces of the Himalaya are but the continuation of Siwalik deposition. This is well seen, according to Middlemiss, in the Ramganga valley in the Patli Dun, Garhwal. Here the river gravels of today are subtended by slightly elevated banks of older gravel, clothed with a certain amount of vegetation and debris of broken driftwood, dead trunks and tangled tree-roots, and now being cut through by the river. Above these are still older terraces spreading in long flat steps one above another over most of the level portions of the *dun*, and largely covered with soil which supports a dense grass jungle. Higher still are the Uppermost Siwalik conglomerates or slightly coherent gravels, gently inclined northwards and flattening out beneath the younger gravels; these obviously mark the existence of the forerunner of the present Ramganga.[100]

The terraces of the Himalayan rivers often form large level plateaux on which towns and villages of considerable size have been built. In the upper Kulu valley, for example, a great thickness of alluvium in which rounded boulders are embedded is exposed at Katrain, the staging bungalow of which village is situated on a high precipice of such deposits overlooking the Beas river, Spiti, and especially the valley of the Spiti river, is characterised by a series

[98] "A sketch of the Geography & Geology of the Himalaya Mountains and Tibet", 261 (1907).

[99] Rec. 9, pt. 2, 55 (1876), Mem. 22, Chapt. 4 (1883).

[100] Mem. 24, pt. 2, 56 (1890).

of terraces, sometimes as many as five, one above the other.[101] In the United Provinces the Kosi is fringed with broad terraces of Recent gravels rising some 200 feet above the river level. In the tributary valleys of Punch are to be seen terrace deposits composed of unstratified or crudely stratified sand, gravel and re-assorted glacial moraine;[102] in the Mandhar and Mahl tributary systems sloping banks of such sand, gravel and shingle reach elevations up to a thousand feet above the valley bottom.

These terraces are not confined to the Himalaya but are found all round the northern and northwestern limits of the Peninsula from Assam to Baluchistan.[102] For example, gravel terraces are a marked feature of the rivers of Hazara, filling broad valleys such as the Haripur plain, the Dore valley, the Abbottabad plain, the Mansehra plain and others, to a depth which must often exceed 300 feet. Gravels of this kind can be traced for long distances up the main valleys such as the Dore and Haro and their tributaries, rising gradually and steadily to heights ranging up to 5,000 feet above sea-level, though the larger plains lie generally between 1,000 and 4,000 feet.[104]

Similar indications are not wanting in other Extra-Peninsular areas. In many of the valleys draining the Shirani Hills of Southern Waziristan, the streams have cut down through the thick deposits of gravel and boulder drift into the underlying country rock which formed the original valley floor on which these detrital drifts were deposited. Furthermore, as the rivers are descended, the slope of the present bed is found to be steeper than that of the old floor. The old valley floor, however, could not originally have been less steep and was probably steeper than the present river gradient, since many of the boulders included in the drift exceed considerably in size the shingle being moved by the stream at the present day. The anomally can best be explained by the inference that a tilt subsequent and parallel to the folding took place after the deposition of the latest Tertiary deposits.[105]

River capture.—Another common feature in the Himalayan drainage, and one which is also a result of its immaturity, is the frequent capture of one river by another, and especially that made by southwardly flowing rivers which have cut back into the Tibetan zone. Several examples of capture could be quoted.[106] Striking instances are seen in the cases of the Arun (already described), the Ganges, the Tista[107] and the Sind river in Kashmir,[108] as well as the Ramganga which was probably once a tributary of the Kosi. An interesting and what might be described as an extreme case of such capture on the

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[101] Stoliczka, Mem. 5, Art. 1, 120 (1865).
[102] Wadia, Mem. 51, 287 (1828).
[103] La Touche, Geol. Mag., New Series, Dec. 5, Vol. 7, No. 5, 197 (1910).
[104] Middlemiss, Mem. 26, 44 (1896).
[105] La Touche, Rec. 26, pt. 3, 95 (1893).
[106] See R. D. Oldham, Journ. Manchester Geogr. Soc., 9, 112 (1883).
[107] Hayden, Mem. 36, pt. 2, 129 (1907).
[108] R. D. Oldham, Rec. 31, pt. 3, 142 (1904).

southern flanks of Kinchinjunga in Sikkim has been recorded by Garwood.[109] "Here the Rathong Chu and Praig Chu, feeders of the Great Ranjit, have cut back their heads so rapidly that they have actually truncated and captured what was formerly an important eastward-flowing tributary of the Tista. So rapid has been the work of these two streams that they have cut deep chasms or gorges across the old valley, with the result that the remnant of this former tributary of the Tista is now only a small stream, which occupies a nearly level upland glen, three miles in length and some 2,000 feet above the floor of the Rathong Chu, and this elevation is maintained nearly to its mouth, whence it empties itself by precipitous cascades into the valley beneath." This piracy on the part of the Rathong Chu has been ascribed to recent elevation of the Kinchinjunga *massif* to the north, an elevation which would have increased the gradient and erosive power of the Rathong Chu without affecting those of the eastward-flowing stream except to give it a sideways tilt. The curious "hanging valley" thus produced, suspended in mid air high above the level of the main valley, would owe its formation in this case at any rate partly to the capture, but its formation may have been assisted by the more recent occupation of the tributary stream by a glacier.

"Hanging valleys" are not infrequent in the Himalaya, the higher carrying glaciers instead of water-courses.[110] In fact, recent occupation by protective ice has in many cases caused, or contributed towards, the formation of "hanging valleys", and prevented their cutting down to the level of the parent stream. Where the side stream is longitudinal and the main river transverse to the mountain chain, every additional spasm of uplift would in certain conditions make the parent valley cut deeper and become more precipitous, without affecting to any extent the tributary valley. Besides the example already given, mention may be made of the "hanging valley" of Yangla Dhar in the upper reaches of the Kali; here a small tributary from Api, a peak within the western border of Nepal, pours a cascade of some volume over a fall of between 300 and 500 feet into the Kali river below. A much smaller "hanging valley" occurs at Tehri where the Bhagirathi has cut down into its rock bottom twenty feet below the bed of its tributary the Behling. Instances of "hanging valleys" have also been noted in the Pir Panjal and in the Lidar valley.

Lakes.—It cannot be said that lakes are a prominent feature of the Himalaya. At the same time, landslips are frequent, especially during the earthquakes which so often visit this region, and in some cases cause the formation of mountain lakes of varying permanency. Lakes, some of them of large size, are produced in this way or by dams of moraine material, and occupy some of the longitudinal valleys. When drained by the cutting back of some stream, they leave behind the wide flat alluvial valleys which offer such a contrast to the drainage elsewhere. The vale of Kashmir is a worthy

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[109] D. W. Freshfield, "Round Kangchenjunga", Append. by E. J. Garwood, 296 (1903).

[110] Rec. 66, pt. 3, 392 (1932).

instance of such a lake basin, in this case not completely drained; the undrained remnants, which are little more than inundation hollows in the river alluvium, are the well known Wular Lake, the double Dal (Bod Dal and Lokut Dal), the Anchar Lake, the Manasbal Lake, and several large swamps or *jhils*. Again, north of the Zoji La, the rugged granite mountains give place to sloping hills and ridges and finally to the wide terraced basin of Kargil, a town surrounded by barley fields and poplar groves;[111] this is part of the old Pleistocene basin of Hundes and has been drained by the Hangru which has cut back from the Indus through the dividing range and now drops steeply along a slope of 200 feet to the mile throughout its 8-mile course to the parent river.[112]

In Kashmir, besides the fresh-water lakes of the Jhelum valley, there are some saline varieties, the most important of which are: the Tso Moriro (Moriri; Marari) in the province of Rupsu, 46 square miles in area, 250 feet in maximum depth and 15,000 feet in altitude; the Salt Lakes of the Lingzi Thang Plains, and the long Pangong Tso (Pagong Tso; Tsomo Gmalari), stretching with interruptions eastwards into Tibet and ending in the fresh-water Nyak Tso. All these are on the Tibetan side of the crest of the Himalaya. There are several lakes in the Pamirs, one of them 140 square miles in area and over 750 feet in maximum depth, but the Karakoram and Hindu Kush contain no lakes of importance. The sacred lake of Manasarowar (133 square miles) and the adjoining Rakas Tal (100 square miles), behind the Nepal Himalaya in Nagri Khorsum, lie 14,900 feet and 14,850 feet above sea-level respectively, and occupy a mountain knot characterised by the culminating peaks of four different ranges; these peaks are Kailas, Gurla Mandhata, Kamet and Nanda Devi. From this mountain region rise the three great rivers of India, the Indus, Brahmaputra (Tsangpo) and Ganges, as well as the largest tributary of the first—the Sutlej; according to Hindu mythology these lakes are the traditional sources of the rivers named, all of which are, in fact, connected with channels that rise in the immediate neighbourhood of the lakes. Between the Nepal Himalaya and the Tsang-po river are the Palgu Tso (40 square miles) at 15,000 feet, and the Tso Motretung (Chomto Dong; 40 square miles) at 14,000 feet. Between the Bhutan Himalaya and the same river are the curious ring-shaped Yamdrok Tso (Palti; 340 square miles) at 14,350 feet, and the Tso Tigu (Tigo; Trigu: 51 square miles) at 15,000 feet; the former is really a double lake, and does not completely encircle the central Tungchen mountain which is connected with the mainland by two isthmuses. The small Kala Tso, S. S. W. of Gyantse, 14,600 feet above sea-level, at one time stretched eastwards for another nine miles and joined the valley of the Nyang Chu at a point whence a broad glaciated valley runs up southwards to the snow-clad peaks of the Bhutan frontier. According to Sir Henry Hayden, extensive moraines now fill this glaciated valley and were left by a large retreating glacier. The deposition of this moraine closed the tributary

[111] De Terra, Mem. Connect. Acad., 8, Art. 2, p. 22 (1935).
[112] Ibid., p. 23.

valley of the Kala Tso and thus produced a lake, the water of which stood at a height of about 30 feet above their present level that left a clearly defined terrace to mark the old shore-line ; desiccation, having set in, persisted steadily and is still in progress.[113] At the Assam end of the Himalaya, on the Tibetan side of the crest-line, are also the Tso Phomo Chang (20 square miles) at 16,050 feet and the Tso Rombudsa (20 square miles).

Some of the above-mentioned lakes, while wholly or partially in Tibet, do not belong to the plateau of Tibet. This plateau is covered with innumerable lakes, nearly all of them salt. The largest lake in Tibet, the Koko Nor, 10,700 feet above sea-level in north Tibet, is 1,630 square miles in area and lies outside the main lake basin. The Isaidam, however, is a dried-up lake basin having an area of 12,000 square miles and occupied by a salt desert.

Three hypotheses concerning the mode of origin of the Tibetan lakes have been put forward :

(1) the damming of river valleys by talus ;

(2) a tectonic rise of the river bed and the consequent deposition of detritus above the barrier so formed ;

(3) the filling with water of a rock basin previously scooped out by a glacier.

With regard to the third hypothesis, rock basins scooped out by glaciers have been recorded in other parts of the world, and the small lakes in the Kumaon Himalaya were at one time supposed to have been formed in this way, but there are no grounds for believing that any but insignificant examples in the Himalaya or in Tibet owe their formation to the sculpture effected by glaciers and ground-moraine. The series of lakes in the long and narrow valley of Pangong were thought by F. Drew to have been formed by dams built up by tributary streams ; this hypothesis was rejected not only by R. D. Oldham but more recently by Ellsworth Huntington, who regards the valley as a true rock basin carved out by a glacier.[114]

Burrard and Hayden came to the conclusion that the curious reversal of drainage observed at the head of the Rong valley in central Tibet seems explicable only on the assumption of a rise of the valley floor near the former outlet of the Yamdrok Tso.[115] They were, however, inclined to doubt the general application of such an explanation and suggested that while some of the Tibetan lakes may have been formed in this way or by glacial scooping, others were the result of the damming of river valleys. The last-mentioned process might have been effected simply by the talus fans of tributaries, as described by Drew,[116] but Burrard and Hayden have advanced a slight modification of this hypothesis which may be of more extended

[113] Mem. 36, pt. 2, 135 (1907).

[114] Journ. of Geology, 14, No. 7, 599 (1906).

[115] A sketch of the Geography & Geology of the Himalaya Mountains and Tibet", 202 (1907), Mem. 36, pt. 2, 134-135 (1907).

[116] "Jummoo and Kashmir Territories", 323-325 (1875).

application. They note that one of the most marked features in the development and growth of a river system is the tendency for branches to capture other branches or portions of other rivers or even neighbouring tributaries by cutting back their channels. "If, therefore, either owing to the beheading of the main stream or to its own vigorous growth by capture, a tributary were to become the predominant affluent of a river system, then owing to its increase of volume and consequent increase of transporting power the amount of material brought down by it would be correspondingly increased. If at the point where it debouched into what was formerly the main valley, the latter were broad and open, its rate of flow would be checked and the transported material might thus be deposited to form a dam across the valley. Such might indeed have been the origin of Tso Morari in Rupshu." In some cases, as for instance in that of Kala Tso, a lake would appear to have been clearly caused by the damming of a valley by extensive moraine material brought down by a glacier from the neighbouring mountains, and it is probable that in many cases the lake dams must be attributed to glaciers rather than to rivers.[117]

The presence of such vast numbers of lakes, however, seems to demand some more generally applicable solution, and is, it is suggested, bound up with the fact that the Tibetan plateau is an area of closed drainage. In the words of Sidney Burrard., "there is no water-parting line between the Indian and the Arcitic oceans ; instead of an elevated line crossing the central portion of the continent from east to west there is a succession of closed basins : the Tibet lake-basin, the Tarim basin, the basin of Lake Balkash, the basin of the Helmand, the Aral basin, and the Caspian. No range of mountains can be found—not even a single peak—from which the water flows on one side into the Indian Ocean and on the other into the Arctic."[117] (*Ibid.*, 201.) Lakes would. therefore, be the natural terminations of the numerous isolated river systems, and would seem to be the inevitable consequences of the closure of the drainage. It is the latter, rather than the existence of the numerous salt lakes, which requires explanation, and this is probably to be found in the combined effects of the desiccation of the Tibetan plateau and corrugating earth movements. That the plateau has suffered severe desiccation there is ample proof. Such desiccation must have been caused in the first place by the rise of the plateau itself and the precipitating effect upon the monsoon clouds along the southern face of the still loftier Himalaya. The behaviour of the monsoon towards a high tableland is well seen in the case of the Shillong plateau, the southern edge of which has an average rainfall of about 458 inches annually, while at the station of Shillong, only 28 miles away to the north on the plateau itself, the average fall is only 82 inches a year. In the case of Tibet this contrast must have been enormously increased by the buckling of the plateau margin to form the colossal range of the Himalaya, the main crest of which now towers on an average 5,000

[117] "A sketch of the Geography & Geology of the Himalaya Mountains and Tibet", 1st Edit. 202, 203 (1907).

feet above the plateau. The monsoon, moreover, now has to cross 90 miles of mountainous country before it reaches the great range of the Himalaya. Little wonder is it that so small an amount of its moisture gains the central portions of Tibet. It seems readily conceivable that the reduction in precipitation has been so great and so rapid that the upper part of the old drainage of the rising area was unable to keep pace with the earth movement and maintain its river courses, and became shut off from the oceans to which it originally had access.

The many salt-covered flats and dry basins on the plateau of Tibet witness to the fact that lakes were at one time even more numerous than they are now. As already remarked, the dried lake of Tsaidam, now a long flat basin filled with saliferous detritus, has an area of 12,000 square miles. Existing lakes were also much larger than they are at present. Explorers record that there is scarcely a single lake which is not surrounded by old terraces and beaches extending round the enclosing hill-sides, sometimes 200 feet or more above the present water level. This shrinkage, which is aided by a very active solar evaporation, is the cause of the intense salinity which characterises nearly all these lakes. Among the salts are common salt, sodium carbonate and borax; the borax and salt are exported in small quantities into India on the backs of sheep and goats. Shrinking seems to have taken place *pari passu* with the gradual diminution of the glaciers, both being to some extent results of the same causes. Whether desiccation is still increasing or not is uncertain. The extraordinary seasonal variation in salinity of some of the lakes makes it difficult to form any reliable opinion on this point. Most of the lakes appear to be permanently salt, the smaller ones markedly so, but the Aru Tso, to the east of Leh, is sometimes salt and at the other times so fresh as to be drinkable.[118] The Pangong was at one time considerably larger than it now is, and a series of old beaches around its periphery witnesses to desiccation in stages.[119] That both the Kala Tso and the Yamdrok Tso have shrunk since their formation is proved by the existence of old terraces at some height above the present lake levels, whilst at the same time the waters of both are slightly though perceptibly brackish.[120] Evidence of shrinkage can also be seen in the Tso Morari and in a great many others of the lakes.

Although most of the Tibetan lakes have no superficial outlet, there is in many cases a well marked channel through the old river gravels which fill the old original outlet. Such a channel, though dry at the time of observation, often shows evidence of recent outflow, and it seems not unlikely that it functions intermittently as an outlet. Such channels can be seen on Manasarowar in Nagri

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[118] H. Bower, "Across Tibet," 35 (1894); H. H. P. Deasy, "In Tibet and Chinese Turkestan", 31 (1901); C. G. Rawlings. "The Great Plateau", 111 (1905).

[119] E. Huntington, Journ of Geology, 14, No. 7, 599 (1906).

[120] Rec. 32, pt. 2, 167-168 (1905).

Khorsum and on the Tso Motretung and Kala Tso behind the Sikkim-*Bhutan Himalaya in Tsang. From the last-mentioned lake outflow also takes place beneath the surface of the deposits through which the superficial channel runs.*[121]

The innumerable glacial tarns found in the still glaciated valleys of the higher mountain region are in almost every instance mere ponds produced by the damming of a valley by the terminal moraine of a retreating glacier.[122]

Of the Kumaon lakes, Khurpa Tal and other small lakes near Naini Tal have been formed by landslips. The origin of the well-known Naini Tal and Bhim Tal is not clear. One suggestion is that they have been formed as the result of the elevation of the lower end of a valley, not necessarily by the gradual rise of the crust but possibly by sudden faulting. Another and perhaps more likely view is that they have been produced by the collapse of the surface over a considerable area caused by the solution and removed by percolating water of the limestone underlying the central part of the valley; such a process is observable on a small scale in many places in the vicinity of Naini Tal.[123] That the lakes could have been produced by damming due to landslips, moraines or river talus seems an untenable theory, at any rate in the case of Naini Tal, since its outlet is over solid limestone *in situ* and not over any form of rock debris. Though small in size these lakes are interesting because of their rarity. Of the four lakes occurring on the Indian side of the crest in the Nepal Himalaya none is over six square miles in area.

Landslides, encouraged by the high rainfall and sometimes of considerable magnitude, are frequent in the mountain ranges of the Himalaya. So common an occurrence are they that the infrequency of permanent lakes resulting therefrom is worthy of comment, and appears to be due in many cases to the rapid silting up of any basins of water so formed, followed by the cutting back of the stream through the dam and the lake detritus, with terraces left as relics on either side. Some of the lakes produced by Himalayan landslides are merely temporary. As an example may be cited a lake formed at Gohna in British Garhwal in September, 1893, when a mass of rock fell from one side of the Birahi Ganga valley, leaving an almost vertical cliff 400 feet in height. This lake, after six months time, was some three miles long, a mile in maximum breadth and about 500 feet deep.[124] It is not indicated on the 16-mile map of 1929 and has no doubt been largely if not entirely filled up with detritus, as was foretold at the time it was formed. A few years earlier, eight or nine miles further up the same valley, a heavy landslip had fallen into another lake, which was called Gudyar Tal and had been in existence for many years; the result was a disastrous flood and the complete obliteration of the lake.

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[121] Burrard & Hayden, "A sketch of the Geography & Geology of the Himalaya Mountains and Tibet". 205 (1907).

[122] *Ibid.* 203.

[123] Rec. 23, pt. 4, 229 (1890).

[124] Rec. 27, pt. 1 and 2, 34 and 59 (1894).

The disappearance of lakes in the self-contained Tarim basin, north of Tibet, and in similar desert areas such as Baluchistan, has been attributed to the increase and the movements of blown sand.[125] The Tarim basin is becoming choked with sand and almost all its rivers now end superficially in its deserts and fail to make any visible issue into the lake of Lob Nor. Such failure is probably more apparent than real since, like many desert tracts, there is no doubt considerable underground circulation, much of the river water finding its way subterraneously into the lake.[126]

Glaciation.—That the climate of the Himalaya has, in the not very distant past, been more severe than it is to-day, is seen in the relics of extended glaciation. The glaciers of the Himalaya and Karakoram, large and numerous as they are, are but reduced survivors of an older and more extensive series of ice-flows, which have left proof of their existence in the form of moraines, perched blocks and glaciated surfaces. Heron, speaking of the Everest area, says that the present glaciers are but puny representatives of their former selves, as shown by the huge moraines which encumber all the northern valleys.[127]

Little is known of central and northern Tibet, but there are indications in Ladakh, Ngari Khorsum and Tsang that southern Tibet and the adjoining portions of Kashmir were recently covered with an almost continuous ice-sheet, and with snow-fields and glaciers such as are now to be found only in the Polar regions. Relics of this are seen in the vast moraines which extend from the northern slopes of Chomoyumo and from Naku La far into the Kampa plain. Broad spreads of talus and moraine also cover the northern slopes of the Lhonak range for many miles beyond the snouts of the present glaciers. In both these areas the deposits have been eroded by streams into impassable vertical-sided gorges, some of them 300 feet and more in depth. Old moraines also spread out into the Tuna plain from Pauhunri, Chomolhari and the Linghsi range.[128] Old moraines between the Yaru plain and the head-waters of the Lachu witness to the same extension of the ice, and many other examples could be quoted.

The contrast of modern conditions is exemplified in the present position of the snow-line which, along the northern or Tibetan flank of the Himalaya, is usually about 3,000 feet higher than it is on the same longitude south of the main crest, a contrast due to the greatly reduced precipitation on the Tibetan side of the axis. At about the middle of the Himalayan arc—*i.e.*, in Kumaon—the snow-line occurs at an altitude of 18,500 feet on the Tibetan side of the great range.

[125] S. S. Burrard, Rep. on Geogr. to the Board of Sci. Advice for India, 1905-06.

[126] A curious example of underground flow is seen in the Perisan Gulf, into which fresh-water enters by invisible underground channels from Arabia; off the coast opposite these channels divers actually go down with *mussaks* or goatsliks which they fill with the fresh potable water before it has had time to mix with the overlying salt water.

[127] Rec. 54, pt. 2, 220 (1922).

[128] Hayden, Mem. 36, pt. 2, 135-136 (1907).

On the north side of the Punjab Himalaya the snow-line has an elevation of 19,000 feet, in the Zanskar, Ladak and Kailas ranges it varies from 18,500 to 20,000 feet, while in the Karakoram it is about 18,500 feet.

In the eastern Himalaya snow-fall is much heavier than it is in other parts and passes may be quite blocked as early as September and are not usually open again till the middle of June; in the north-western section, on the other hand the fall on passes between 17,000 and 19,000 feet is never generally more than three feet. Characteristic features of the inner Himalaya are the U-shape of the valleys once occupied by glaciers and the V-shape of the same valleys lower down in their course.

The general diminution of the glaciers on the southern flanks of the Himalaya has been oscillatory but, although some glaciers seem to be stationary and a few even advancing, most of the large ones show distinct evidence of secular retreat during historical times, and computations made during the last few decades show that this retreat is in most cases still in progress. On Makalu, near Mount Everest, two at least of the main glaciers, flowing to the Karma valley, show indications of recent advance.[129]

The Yengutsa and Hassanabad are two glaciers in the western part of the Karakoram which show signs of recent advance.[130] Similar advance is shown by the Chong Kumdang and possibly by the Biafo, the latter, 37 miles long, descending from an enormous snow basin.[131] It is, however, not always easy to distinguish true secular movement in a glacier from periodic movement caused by short cycles of climatic variation, from mere seasonal movement, or from accidental change produced by an avalanche or earthquake. Summing up the evidence in the Karakoram, K. Mason concludes that, with the exception of the Biafo which is too much subject to periodic fluctuations of the snow supply to be a trustworthy example, eight out of nine glaciers investigated are either stationary or show very slight secular retreat, according to measurements made during the past thirty years.[132] During the past few centuries, many of the glaciers of the Karakoram have experienced periodic changes which may be connected with fluctuations in the monsoon; the periodicities of these movements vary from 45 to 55 years.[133] Auden's conclusion is that many of the lateral and hanging glaciers in Baltistan appear to be in retreat.[134]

Evidence of general retreat may take the form of old high-level moraines or glaciated pavements. There are signs not only of general retreat but also of reduction in size of the glaciers as indicated by the occurrence of smoothened and scratched rock surfaces on the valley sides at levels considerably above those of the present ice.

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[129] Heron, Rec. 54, pt. 2, 220 (1922).
[130] Rec. 35, pt. 3, 126 (1907).
[131] Rec. 63, pt. 2, 221 (1930).
[132] Rec. 63, pt. 2, 221 (1930).
[133] *Ibid.*, 271, 273, 275.
[134] Rec. 68, pt. 4, 407 (1935).

While the present limit of glaciers on the Indian side of the Great Himalaya is usually between 11,000 and 13,000 feet, the present snow-line varies in altitude from about 14,000 feet in the eastern parts (15,000-16,000 feet in Sikkim; 15,500 feet in Kumaon) to about 17,000 feet in the west (Punjab Himalaya); these heights being greater than the average height of the Lesser Himalaya, which is 12,000 feet, the latter zone is devoid of glaciers except in the Pir Panjal where a considerable portion of it lies above the snow-line and there are numerous glaciers.

In spite of the general rise of the snow-line, passing from east to west, it is in parts of Kashmir that we find transverse glaciers descending to levels as low as 8,000 feet which, as Wadia remarks, are not far above villages and fields.[135] We have then the peculiarity that, in spite of the fact that Kinchinjunga near the eastern end of the chain is 7° of latitude nearer the equator than Nanga Parbat at the western end, the snow-line shows a general rise from east to west. On the other hand, the lower limit of glaciers sinks from east to west, a result to be expected from the change of latitude and perhaps also from the fact that, although the moisture precipitated in the eastern Himalaya descends for the most part in the form of rain and not of snow while practically the whole precipitation in the west takes the form of snow. The amount of moisture falling in the east, even in the form of snow, however, is considerably greater than it is in the west.

General statements regarding glacier limits and even snow-line are made difficult by the number of interfering factors. The steeper its slope or the larger its volume, the lower will a glacier flow. Even the snow-line is affected by such considerations. The depth of accumulated snow is a problem which is complicated by the shape of the peak supplying the slopes with snow. For example, while snow will not lie in any quantity on peaks as sharp as K_2, Nanga Parbhat or Rakaposhi but descends in avalanches to lower levels where it hardens into ice, on rounded flatter tops such as the Tirich Mir group of elevations snow accumulates in great masses.

In the Pir Panjal, which forms part of the Lesser Himalaya of Kashmir, there is clear evidence, in the form of old moraines, striated and polished rock surfaces and erratics, of extensive glaciation at a period corresponding more or less to the Pleistocene Glacial period of Europe and America. Along the northeastern slope of the Pir Panjal, exposures of solid strata are in places extremely rare by reason of old stranded moraines which effectually hide the country rocks and are in a wonderful state of preservation. Although this ancient glacial deposit in its lower part "fades imperceptibly into the train of boulders occupying the stream beds, there comes a position, varying between the 10,000 and 11,000 feet levels, where, constituted as it is of partly re-made and re-sorted moraine, it covers the north-east slopes of the range in a continuous belt of intermingling debris, streams and fans. At still higher levels, between 11,000 and 12,000

[135] "Geology of India", p. 14 (1926).

feet, the same material, but in its more original unsorted state, is found debouching from the numerous higher valleys in pairs of beautifully regular lateral moraines 500 feet thick. And yet these points of emergence of the stranded moraines are now several miles from, and 2,000 feet below, the present-day belt of live ice and active moraines. The sole contrast between the old and the recent moraines is that the former are uniformly grassed over, and even partly forest-covered with scanty birch trees and dense clumps of stunted juniper. In all other respects these vast superficial ice-formed accumulations appear to have hardly changed their original contours at all since first made." "The vast amount of old grassed moraines at Gulmarg and the similar but steeper forest-covered moraines constituting the slopes between Gulmarg and Kilanmarg and which here and there develop flat *margs* or grazing grounds, must have been derived from the 15,000 foot snowy peaks near Toshmaidan and the Zamar pass. Looking up from Kilanmarg, the valley which runs north from those peaks by Penjian of the Atlas sheet to join the Ferozepur *nullah* can be seen in its upper reaches to be a typical smoothed U-shaped one, and may well have borne a large glacier. The deep *nullah* to the S.E. of Gulmarg may also have contributed, but it must have been cut down to its present deep level since that time. The old moraines apparently had their downward limit just at Gulmarg, where was the lowest melting point of the ice. The other grassy flats between the Gulmarg and Kilanmarg probably represent stages in the recession of the glaciers."[136]

The glaciers on the Babeh Pass, now barely more than a mile in length, at one time extended for at least fifteen miles and probably farther. On the southern slopes of the Dhauladhar a moraine was found by McMahon at an elevation of only 4,700 feet.[137] Grooved and polished rock surfaces have been found at as low a level as 7,500 feet in the Punjab Himalaya.[138] In the Kangra valley, where the high mountains rise steeply from the low ground at their foot, there is reason to believe that the glaciers once reached down below 2,000 feet above sea-level.[139] A still lower level, as we have already seen (p. 2099), may have been attained in the Potwar. In valleys such as the Saraswati and Alaknanda the withdrawal of the ice, which at one time must have descended as far as Badrinath, has been great since the period of maximum glaciation.[140]

The uplands to the north of Sikkim and Bhutan furnish abundant evidence of the former greater extent of glacial conditions in the trans-Himalayan region.[141] This is seen in the old moraines, erratics, old lake basins, and many other phenomena indicative of glacial

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[136] Middlemiss, Rec. 41, pt. 2, 123 and 131 (1911).

[137] Rec. 15, pt. 1, 49 (1882).

[138] C. A. McMahon, Rec. 14, pt. 4, 310 (1881).

[139] Rec. 9, pt. 2, 56 (1876).

[140] Gilbert & Auden, Rec. 66, pt. 3, 394 (1932).

[141] Rec. 32, pt. 2, 167 (1905).

action. Throughout the plain of the Yaru river, around Kampa Dzong, characteristic *roches moutonnées* show the direction of flow of old glaciers from the northern slopes of the Himalaya. At the same time erratic blocks of granite stranded on the hills, now at a height of several hundred feet above the surrounding plain were probably derived from Kinchinjunga and its neighbourhood. On the north flank of Chumalhari too, old moraines extend for many miles beyond the limits of the now comparatively insignificant glaciers, into the Tüna plain. South of the main range, Hooker's observations on the well-marked moraines in the Yangma and Khunza valleys prove the former has much greater extension of the glaciers west of the Singalia watershed, as well as to the east, down to the 8,800-foot contour level.[142] Professor J. W. Gregory has recorded the discovery in a newly excavated cutting of a *roche moutonnee* showing typical glacial grooves and striae, about eight miles north of Darjeeling, at a height of not more than 3,600 feet.[143]

In the Everest region, according to Wager, there is a zone of former glaciation characterised by U-shaped valleys now largely remodelled by scree, and by frequent lakes either moraine-dammed or scooped out of the rock-floor; this zone occurs between 10,000 and 16,000 feet and is well seen in eastern Sikkim in the neighbourhood of the Natu La and Jelep La, and again on the western frontier of that State. One of the most conspicuous features of the southern flank of the high Himalayan zone in Sikkim, and the cause of the frequent small avalanches, is the large snow-fall which piles up snow and ice on the steepest faces of the mountains. Wager notes that in the foot-hills and southern part of the main Sikkim range, where there is rapid water and ice erosion, differences in hardness and resistance to weathering of the rocks, factors of importance in the arid climate of Tibet, play little part in controlling the shape of the mountains and their valleys.[144]

Dainelli has established the former existence of four Glacial and three Inter-glacial periods in the Himalaya, and De Terra's recent observations in north Kashmir tend to support this conclusion.[145] The latter authority dates the 1st. Glacial period, with terminal moraines at an average altitude of 5,500 feet, as corresponding to the Tatrot stage of the Siwalik series. He equates the 1st. Inter-glacial period with the Pinjor or Lower Karewah, the 2nd. ice advance with the Boulder Conglomerate, the Narbada Alluvium, or the boulder clay and gravel in the Karewahs, while the long 2nd. Inter-glacial period is made to correspond with the Upper Karewahs, and the 3rd. ice advance, with terminal moraines at 6,500 feet, with the Upper Narbada Alluvium and the Potwar Silt. Following the 3rd. Inter-glacial period is that of the 4th. ice advance with terminal moraines

[142] D. Freshfield, 'Round Kanchenjunga"; Append. by E. J. Garwood, p. 276 (1903).

[143] Geol. Mag, New Series, Dec. 6, Vol. 6, No. 9, 398 (1919).

[144] Ruttidege, "Everest, 1933, 313-314 (1934).

[145] R. D. Oldham in 1904 had recognised three periods of glacial extension in Kashmir. Rec. 31, pt. 3, 142 (1904).

at 8,000-10,000 feet.[146] Evidence of these periods is described by De Terra in the terraced Kargil basin of Kashmir.[147]

The positive and incontrovertible proofs of a period colder than the present do not point to a sufficient diminution of temperature in the Himalaya to make it probable that glacial conditions prevailed at any late Tertiary or any post-Tertiary epoch in the Peninsula. A general refrigeration of the earth's surface sufficient to produce an arctic climate in Europe would not diminish the temperature of the Indian Peninsula beyond the average of the present-day temperate zone.

Great and numerous as are the Himalayan glaciers, none of them exceeds a length of 20 miles. The longitudinal glaciers of the Karakoram, on the other hand, support the greatest ice-flows in the world outside the Polar regions, the Siachen glacier, 45 miles long and having a fall of 194 feet per mile,[148] exceeding the Inylchek glacier of the Tian Shan by a mile. If they include the "Snow Lake", the Biafo has a length of 37 miles, while the Baltoro, the Hispar, the Batura and the Chogo Lungma are, respectively, 36, 38, 36 and 24 miles long. All the glaciers mentioned flow longitudinally in the direction of the strike of the Karakoram, and terminate generally at higher altitudes than do the transverse glaciers; the Baltoro is a dendritic type of glacier with many compound affluents. Some half-a-dozen further names of glaciers belonging to this snowy range and exceeding a length of 20 miles could be added to this list. The Chogo Lungma, Hispar, Biafo, Baltoro and Siachen, occur in the curving trough between the Karakoram and Kailas ranges; the Batura, on the other hand, lies on the north side of the Karakoram.

The longest glacier in the Sikkim Himalaya is the Zemu, 16 miles long, flowing into the Tista; in addition to this are the Kinchinjunga, 13 miles long and the Yalung 10 miles, both entering the Tambar. The Zemu is the only easily accessible glacier that descends directly from Kinchinjunga. It lies on the northeast side of the mountain and drains at the same time the northern slopes of Simvu (22,300 feet) and the Siniolchum peaks (22,570 and 21,450 feet). Most of this glacier is completely hidden from view by thick moraines; the lateral moraines are separated from the hillside by natural trenches, the origin of which is not clearly understood.[149] The former much greater bulk of the Zemu is attested by the rows of old lateral moraines, one within the other, marking successive stages in diminution; no less than five such old lateral moraines were counted by Professor Garwood in 1899.[150] The best known glacier on Mount Everest is the Rongbuk, descending on the north. Of the glaciers of Nepal there is very little positive information. In the Kumaon Himalaya the largest is the Gangotri, which, after flowing for over

[146] "Nature", Vol. 137, p. 687, (1936).
[147] Mem. Connect. Acad., 8, Art. 2, 41 (1935).
[148] K. Mason, Rec. 63, 260 (1930).
[149] Rec. 40; pt. 1, 60 (1910).
[150] D. Freshfield, "Round Kangchenjunga"; Append. by E. J. Garwood, p. 233 (1903).

THE UPPER PORTION OF GANGOTRI GLACIER WITH CHAUKAMBA PEAKS AT ITS HEADS.

20 miles along a longitudinal trough, enters the Bhagirathi at Gau Mukh; the Kedarnath glacier, 9 miles long, is an affluent of the same river, while the Mana, 12 miles long and expanding along part of its course into a large sheet of ice and moraine, feeds a branch of the Bhagirathi. Other glaciers of this section are: one flowing round the northern end, another round the southern base of Nanda Devi, each of them 12 miles in length and each tributary to the Dhauli (Alaknanda); the Milam, a glacier of the same length, flows into the Gori (Kali). In the Punjab-Kashmir section, the longest appears to be the Durung which is 14 miles long and, with the shorter Rundun (12 miles), enters the Suru. The Northern and Southern Rupal, 10 and 11 miles long, respectively, enter the Indus, cutting off Nanga Parbat from the rest of the Great Himalaya. Some eight additional Punjab and Kashmir glaciers attain a length of 10 miles or more, and there are many smaller.

The Sakiz Jarab glacier in the Hindu Kush is 19 miles long, the Tirich Mir 14 miles long, the Rich 10 miles, the Sad Istragh 8 miles and the Wasmu 7 miles, all draining into the Kunar; the Kurkulti, 10 miles long, drains into the Hunza river.

Glaciers flowing transversely to the strike of the Himalaya are naturally shorter, steeper, and more sensitive to seasonal variations in temperature since they reach lower levels than the longitudinal glaciers. The levels reached vary from one end of the chain to the other. At the eastern end, where the latitude is in the neighbourhood of 28°N. and where the moisture of the monsoon, unchecked by lesser ranges, falls in full measure upon the great range more in the form of rain than of snow, it is seldom that a glacier descends below the 13,000-foot contour. At the western end, on the other hand, in a latitude of 36°N., where precipitation, though much less in amount than it is in Sikkim, all takes the form of snow, and where slopes are generally steeper, transverse glaciers descend considerably lower. In the Karakoram they frequently descend to 10,000 feet and sometimes to 8,000 (Hassanabad, 7,290 feet), or even, as in the case of the Minapin glacier, to 7,000 feet;[151] some of the Kashmir glaciers usually melt before they reach 11,000 feet. Longitudinal glaciers end usually at higher levels than do the transverse, as already stated, with the exception of those of the former category whose immense volume of ice enables them to survive for a longer period the attacks of the heat.

The dirty colouring and dirt-banding so conspicuous in Himalayan glaciers is a result of the immense quantities of dust blown up by the winds from the desert, plains and foot-hills below. The dirt bands are probably seasonal and denote annual variation in dust accumulation. Such banding is often well exposed in the snout of the glacier which usually terminates in an ice cave; the latter is often found at the end of a large tunnel along which flows a considerable amount of subglacial and englacial drainage. The surface of most glaciers is also extensively covered with dirt and moraine which often conceal the

[151] Rec. 35, pt. 3, 125 (1907); *Ibid.*, 63, 230 (1930).

ice for long stretches. Upon these superficial deposits overlying the glaciers in Kashmir it is a usual thing for shepherds to encamp during the summer months with their flocks.[152]

The peculiar deep trough-like pot-holes known as "giant's kettles" and eroded out of the solid rock by sub-galcial water flowing from the bottom of one crevasse to another, have been recorded by Col. Grinlinton in the old glacial floor of the Lidar valley in Kashmir; one of these is described as large enough to hold three men.[153]

Origin and history of the Indus, Brahmaputra and Ganges.—An accompaniment of the accumulative mountain building along the northern fringe of the old Gondwana continent was the formation of a long belt of persistent subsidence between the mountain range and the more central tract of the continent. The vast thickness of the Siwalik deposits, all of which were formed sub-aerially and even after the elevation they have undergone now, only reach a very few thousand feet above the sea, can only have been formed in an area which was gradually subsiding as the deposits were piled up. This vast trough, in which the Tertiary and Quaternary deposits were laid down, is bounded on the north by reversed faults or thrusts, and may be looked upon as a faulted geosyncline, of which the southern slope is a long and gentle one, while the northern is steep, much shorter, probably stepped, inverted and overthrust. It is doubtful whether this trough was appreciable before the Eocene period, since when it has become increasingly deeper and filled up simultaneously with accumulating sediments, until today its calculated maximum depth is between 15,000 and 20,000 feet. As we have seen, the rock floor on which the Gangetic alluvium rests is only 513 feet below the surface at Agra, a city not far from the southern edge of the alluvial tract. At that particular point, therefore, the floor in question is only 5 feet above sea-level, a fact which indicates that the bulk of the Gangetic alluvium further north lies below the level of the sea and that the maximum depth of this floor must occur many thousands of feet below the same datum line. Stretching from Assam to the Punjab and thence to the Arabian Sea, the Indo-Gangetic trough would in its earliest stage have formed a natural hydrographic line. West of the Jhelum, the buckling effect which produced the trough seems to have dissipated itself over a wider area. This hydrographic line has been pushed in stages steadily towards the centre of India. Along the Himalaya these stages were narrow and the trough deep, but in the central Punjab, North-West Frontier, Baluchistan and Sind, the stages were wide and the trough area shallow.

There is a continuous outcrop of Eocene beds extending from the Hazara hills through Kohat, Waziristan and Baluchistan to the Sind coast; east of Hazara, Eocene-Oligocene beds again appear and can be traced with interruptions along the foot of the Himalaya through the Simla region to a final very thin band between Dehra Dun and Naini Tal. These early Tertiary sediments accumulated in an arm of

[152] Wadia, "Geology of India", p. 15, (1926).

[153] Mem. 44, pt. 2, 306, 355 (1928).

the sea or gulf. Restoring in our mind's eye the mountain arcs to the less advanced position they must have held in these early Tertiary times, and reducing the syntactical angles which separate these arcs from each other, we can trace the gulf from Sind and Baluchistan, over parts of Bikaner, to eastern Afghanistan and the North-West Frontier, curving thence eastwards through the Punjab along the foot of the Himalaya as far as Naini Tal. The Eocene of Ladakh and Hundes appears to belong to a separate basin of deposition, and the Eocene of the Shillong plateau of Assam to yet another basin in which sediments were laid down in a gulf extending up from Arakan.

In the depression along the continuous system of mountain arcs a constant struggle took place between the deposition of silt tending to fill up the gulf, and the general subsidence tending to deepen it. Early in the life history of the gulf, silting became localised to such an extent as to cut off land-locked salt lagoons, a process which may have been assisted by the corrugation of the gulf floor into small anticlines and synclines in addition to the general depression of the whole area as a geosynclinorium. Much of the Kumaon and Simla Subathu, as well as most of the Upper Nummulitic (Chharat) of the Potwar and Hazara, appears to have been deposited in such salt lakes and lagoons.

East of Naini Tal in Eocene times the hydrographic line must have been occupied either by an extension of the marine gulf south-eastwards, or by a separate marine gulf stretching in the same direction, or by a river. The thinning out south-eastwards of the Subhathu beds in the direction of Naini Tal, where they are not more than a few hundred feet in thickness, is against any eastern extension of the Punjab gulf, though it must be confessed that we know nothing of what lies beneath the great thrust-planes which have brought the pre-Tertiaries considerable distances to the southwest. To explain certain geodetic anomalies, it has been suggested that there is a slight but appreciable rise in the floor of the trough fronting Dehra Dun and in line with the not very distant remnants of the Aravalli range. On each side of this supposed rise, which has been attributed to a northeasterly prolongation of the Aravalli relief, the trough is said to resume its normal depth. Whether or not there was any such low rise at or near the head of the gulf, we find no evidence of any Eocene sea along the foot of the Himalaya from Naini Tal to Assam, though again it must be emphasised that much of the country is unexplored, and much of its rock sequence lies buried beneath thrusts and alluvial deposits. The probabilities are, perhaps, that the eastern half of the trough or hydrographic line along the Himalayan foot-hills was occupied by an Eocene river whose sediments have not as yet been identified as such among the rocks of Nepal and beyond or lie concealed beneath thrust-planes or under Siwalik or Recent alluvial deposits. Assuming that the eastern half of the trough was occupied by a river, the question arises: Did it flow westwards into the head of the Punjab gulf, or did it flow eastwards from a low watershed coincident with the supposed extension of the Aravalli hills?

If it flowed eastwards, the only likely outlet to the sea would have been through the gap between the Rajmahal and Garo hills, along the present course of the Ganges. It is, however, generally supposed that the gap in question is of geologically recent date, though the evidence for this assumption is mostly of a negative character. On the west side of the gap there are no relics of Tertiary deposition, but on the east the outcrop of Eocene with an accompanying patch of Siwaliks, and still more noticeably an inner-lying belt of Cretaceous, can be seen curving up into the gap from the Shillong plateau margin. According to a recent survey by Fox, the land which extended over the Shillong plateau area at the close of the Cretaceous period began to subside during the Eocene. There ensued the deposition, probably under marshy conditions, of the coal measures and of kaolin, followed by limestones and shales; at the time the Sylhet Limestone was laid down, a large part of the plateau area seems to have been under the water of the Bay of Bengal.[154] The Shillong plateau is thought to have been warped by the southward thrust of the Himalaya; its southern edge became a monoclinal fold in the Khasia Hills and an overfold and thrust-fault in the Garo hills to the east.[155] Fox describes several important N.-S. faults which slice the Garo Hills and displace both the Tertiary strata and blocks of gneiss *en echelon,* each block to the east being a little southward of that to the west. The indications, in fact, are those of shearing or tear-faulting, which was accompanied by E.S.E.-W.N.W. faults responsible for the preservation of coalfields, such as the Daranggiri and Rongrenggiri.[156] If we are to accept the hypothesis outlined at the beginning of this paragraph, we should have to conclude that the Rajmahal-Garo hills gap is much older than has been supposed,[157] that when the margin of Gondwanaland started to buckle, the north-eastern end of the old Aravalli range preserved its function of a watershed, dividing an Eocene gulf to the northwest from a south-easterly-flowing river which, after receiving another river from Assam—the fore-runner of the Brahmaputra—passed through the gap and emptied itself into the Bay of Bengal, as the Ganges does today, and that, when the Eocene gulf was replaced by a river in the Nimadric (Murree-Siwalik) period, the precursor of the Ganges continued its southeasterly course.

The alternative possibility has been elaborated both by G. E. Pilgrim and the writer.[158] According to this, the hydrographic line from the Punjab Eocene gulf eastwards right up to the head of the Assam valley was occupied by a river flowing westwards and draining into the gulf. During the Nimadric period the Eocene gulf dried up and was replaced by a river flowing north-westwards along the foot of the Punjab Himalaya, across the Potwar and down through Baluchistan

[154] Rec. 71, pt. 1, 84 (1936).
[155] Rec. 72, pt. 1, 92 (1937).
[156] Rec. 71, pt. 1, 83 (1936).
[157] Man. 2nd Edit, 444 (1893).
[158] J.A.S.B., New Ser., Vol. 15, pp. 86-99 (1919); (Q.J.G.S.), Vol. 75, 138-155 (1920); Mem. 40, pt. 3, 450-473 (1920).

and Sind to the Arabian Sea. Of the existence of this riverine tract from the vicinity of Naini Tal to the Arabian Sea there can be no question. That this river was continuous with the supposed river from Assam and formed therewith a single continuous stream throughout the whole length of the Himalayan base from Assam to the Punjab and thence to the Arabian Sea, is a less substantiated hypothesis. Nevertheless, with reservations as to what future discoveries in the foot-hills of Nepal may disclose, and admitting our ignorance of the depth of the Rajmahal-Garo hills gap,[159] and of what Tertiaries lie beneath the Ganges alluvium and the thrusts of the lower Himalaya, the idea is not unsupported by some of the indications available.

In the first place, there is no evidence to show that the end of the Aravalli range offered any serious obstruction to the buckling of the edge of the Gondwana continent. The only signs of the influence of the Aravalli on the Himalayan folding are the somewhat doubtful N.E.-S.W. alignments of pebbles and structures. There is nothing to match the syntaxes which form such conspicuous features at various obstructive points on the Gondwanaland margin elsewhere, nor is there any but insignificant interruption in the general strike and trend of the rocks of the Himalaya and the ranges they occupy. Geodetic anomalies are responsible for the suggestion that there is a small local rise in the trough floor opposite the Aravalli range, and another similar slight sub-alluvial barrier across the trough between the Garo Hills and Bhutan, but there is no accompanying displacement in the regularity of the folding nor any evidence against the view that the trough along the Himalayan foot-hills is continuous eastwards from Kashmir to the head of Assam.

It is this regular disposal and continuity of outcrop of the Nimadric and especially of the Siwalik sediments which to the writer is so suggestive of a single continuous river, to which the provisional name of "Indobrahm" has been given. From Assam to the Punjab the continuity of physiographical and geological features is striking. There is a continuous regular mountain arc of ancient rocks on the north ; there is a parallel upland of similar ancient rocks on the south, continuous beneath the presumably shallow gap between the Rajmahal and Garo hills ; between this mountain arc and the upland is a continuous outcrop of Alluvium of great maximum thickness, occupying a continuous trough, and succeeding what, there is no reason to doubt, is a continuous Upper Tertiary river deposit which exhibits a remarkable uniformity of lithological composition and homogeneity throughout the length of the range. The sub-alluvial barrier, supposed to exist to the N.N.E. of Delhi, interrupted neither the continuity of the Siwalik deposition nor that of the Alluvium, nor indeed that of the Eocene. There is no rock barrier in the plains at the present day between the basins of the Indus and the Ganges, the watershed being a scarcely perceptible one.

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[159] According to geodetic computatious the depth of alluvial deposits over the gap, whether Tertiary or Recent, is comparatively small (Oldham. Mem. 42, pt. 2, 81 (1917).

Earlier in this chapter mention was made of the fact that the boulders of the uppermost Siwalik stage show signs of being more numerous in the vicinity of large rivers debouching from the hills. True though this may be, it must not be supposed that they are limited to such areas. As Pilgrim points out,[160] this is very far from the case and, although the local increase in the Boulder Conglomerate from place to place may be due to the explanation given (p. 1801), this explanation is insufficient to account for the enormous thicknesses reached by these deposits in areas remote from the modern Himalayan rivers. Broadly conceived, the maximum development of these beds occurs in the tract of country between the debouchures of the Beas and Chenab, where they form a large proportion of the low hills bordering the plains and attain a thickness of more than 5,000 feet; here also they are exposed over a width exceeding 60 miles, and this may readily have been the actual width of their outcrop originally. Northwest of the Chenab the deposits disappear quite suddenly; southeast of the Beas they diminish gradually in thickness in a general way and are feebly represented as far east as Bhutan. Pilgrim accounts for the excessive thickness, greater coarseness and immense width of outcrop of the Siwalik boulder deposits in the Beas-Chenab sector by supposing that the parent river, postulated as flowing north-westwards along the base of the Himalaya in late Siwalik times and as receiving the Himalayan rivers as tributaries with their loads of boulders, was dammed back by a local upheaval to form a rock basin in which the boulders accumulated until the gradient was restored. The formation of such a dam might well have been produced and directed by the obstruction offered to the Himalayan movement by the Jhelum syntaxis.

To continue the hypothetical story, it is supposed that at some time or other two separate rivers or two branches of the same river, debouching into the Bay of Bengal, cut back between what are now the Rajmahal Hills and the Garo Hills and beheaded the westerly-flowing "Indobrahm", the eastern capturing the Assam portion to form the Brahmaputra, and the western capturing gradually piece by piece the portion that intervenes between Assam and the present Jumna, cutting back along the already excavated channel, capturing this channel piece by piece and its tributaries one by one, and completely reversing the direction of its drainage. One of these capturing streams was the Jamuna or Bengal part of the Brahmaputra, and the other either a tributary of this river or a separate stream, the Ganges. These rivers present the appearance of having been initiated by the continuation northwards of the broad geosyncline of the Bay of Bengal which is still an area of depression. Perhaps with the assistance of the Shan movement from the east, which produced the geosyncline, perhaps with the help of shears or faults, both streams cut back through the barrier of ancient rocks which connected the Rajmahal with the Garo hills. The Jamuna captured the upper part of the "Indobrahm" from Dhubri to the upper end of the

[160] J. A. S. B., New Series, Vol. 15, 87 (1919).

Assam valley, and this captured section became the modern Brahmaputra. The Ganges cut back in a W.N.W.'ly direction, capturing element by element the succeeding portion of the "Indobrahm" as far as Hardwar, where the Alaknanda was annexed, the Jumna at that time being the head-waters of the Ghaggar. This capture by one river of another flowing in the reverse direction would have been facilitated by the continued sinking of the trough occupied by both. The voluminous waters of the Upper "Indobrahm" having been tapped in this way, the scouring of a broad gap through the barrier would have been an easy matter, and the sediments derived therefrom would have been flung into the Bay to form the enormous delta of the Ganges and Brahmaputra. A definite case has been stated for the sake of clearness, for obviously there are equally valid alternatives of detail. It may, for instance, have been a single river which cut back through the barrier, beheaded the "Indobrahm" and became the Brahmaputra, the Ganges originating north of the gap as a right bank tributary and cutting back north-westwards in the way described, the confluence subsequently retreating southwards through the gap.

As an indication that the main river along the Himalayan foot originally flowed north-westwards, Pilgrim cites the local V-shaped course of many of the present rivers from the mountains as they cross the Siwalik belt, the angle of the V pointing north-westwards and occurring usually close to the boundary line between the Siwaliks and the Alluvium. The northern limb of each V may be regarded as the remnant of a right-bank "Indobrahm" tributary, which has persisted in its old westerly direction, having become more deeply impressed and permanent owing to the upheaval of the Siwalik deposits over which it flows. The southern limb of the V would represent the final position assumed by the junction of the tributary with the usurping parent river, for, if the deduction that the actual capture of the parent river by the Ganges happened subsequent of Siwalik times be correct, it must have taken place within the outcrop of the Alluvium—that is to say, the point of the V at the time of capture was west of where it now is but has since worked eastwards until it met the more stable topography of the Siwalik belt, where its further regression was in most cases held up.[161]

The presence today in the Ganges and Indus of the same species of dolphin—*Platanista gangetica* Lebeck—which has evidently acquired a fresh-water habit, it accepted by the writer as a proof of an organic connection at some time between the Indus and Ganges basins. This cetacean, which is found only in the Ganges, Brahmaputra and Indus and never enters the sea, is of a very different generic type from the *Orcaella brevirostris* Owen inhabiting the Irrawaddy; the latter is known to be a marine form which makes its way

[161] The higher parts of the courses of these mountain rivers—the portions traversing the older pre-Tertiary rocks are of course not relevant to this question. The argument is concerned solely with the direction of the tributaries from the point at which they enter the Siwalik—Alluvium outcrop to the point at which they join the parent river.

for long distances upstream, not only in Burma but also in Bengal and Siam. *Platanista* is not found in the Mahanadi, the next important river south of the Ganges to enter the Bay of Bengal from Peninsular India. Oldham, in the second edition of this Manual, notes that the capture by the Ganges of the upper Jumna, which was at one time a member of the Indus drainage system, would have provided a connection between the Indus and Ganges basins only in the torrential regions unfrequented by such cetaceans. This objection, however, is of doubtful validity, since there would have been ample room for the capture to have taken place in the alluvial belt where conditions would not have been torrential but those of gentle, comparatively sluggish gradients; the width of this alluvial belt today is over a hundred miles. In any case the difficulty disappears on the assumption that, earlier than this, the organic connection between what are now the Indus and Ganges was a large continuous river. Annandale has called attention also to the resemblance between the *Chelonia* of the two rivers, those of the Indus being identical with those of the Ganges, whereas those known from the Mahanadi, for example, belong to distinct sub-species or local races. This was found to be particularly noticeable in the case of *Trionyx gangeticus* Cuvier, one of the commonest and largest forms in the three rivers mentioned.[162]

Transferring our attention to the other flank of the Himalayan chain, we note the backward direction of many of the present tributaries of the Tsangpo or upper portion of the Brahmaputra. The most recent maps show that shortly before their junctions with the Tsangpo these tributaries bend from their abnormal backward courses and turn towards the present direction of flow of the parent river. The most important tributaries having a backwardly directed course are the Kyi or Lhasa, the Nyang, the Rang and the Shang, but there are several smaller ones that exhibit the same peculiarity. The impression given is that the Tsangpo originally flowed westwards instead of eastwards, and has had its channel reversed by piecemeal capture on the part of some river from the south—perhaps the Chindwin-Irrawaddy, perhaps the Meghna, perhaps the Indobrahm, perhaps each in succession. Burrard and Hayden suggest three hypotheses worthy of consideration regarding the former outlet of this old westward-flowing Tibetan river, viz.: (a) that it flowed over the Photu Pass and through the defile of the Kali Gandak on to the Ganges plain; (b) that it passed through the basin of the Karnali with a similar destination; or (c) that it followed the present Himalayan course of either the Sutlej or the Indus. It is perhaps idle to speculate far in this direction, but an examination of the map will show an interrupted hydrographic line from Pemakoi to Gilgit, represented today by the Tsangpo (perhaps including the Raga tributary and a small branch of the Chaktak), the Manasarowar lakes, the Uppermost reaches of the Sutlej, the old structural depression of the upper Indus from Hanle to Kargil and thence across the Burzil Pass area. That this line was once a continuous drainage line sloping

[162] Bijdragen tot de dierkunde Amsterdam, Afl. 22, 145 (1922).

westwards seems at least not improbable.[163] To it belong the marine and fluviatile Eocene of Ladakh, corresponding in position to the Eocene of the hydrographic line on the other side of the Himalaya, and indicating that the Tibetan line is as old as the Indian. The thick Pleistocene deposits of the uppermost reach of the Sutlej also belong to it, and are obviously the detritus of a larger stream than the present upper Sutlej which, moreover, is out of all proportion to the great cañons it occupies. The suggestion is that the Tibetan line was formerly occupied by a river which rose somewhere in or near Pemakoi, and either joined the Oxus, or found its way to the Arabian Sea, independently or by way of the "Indobrahm." At the present day the Indus at Bunji, where it abandons its north-westward course and turns southward, is 3,400 feet lower than the Tsangpo-Brahmaputra where it leaves the same geo-tectonic line at the other end of the Himalaya[164] From Mayum town above Lake Ukrang east of the Manasarowar Lakes, to Bunji, the average westward gradient is twice as steep as it is from Mayum eastwards to the point where the present Tsang-po turns southwards. In spite of its immense elevation the Tsang-po is a sluggish and navigable river south of Lhasa, and has cut no deep basin for itself in Tibet. The Indus, on the other hand, following for thirty miles the plane of overlap between the basal beds of the Flysch and the granite gneiss of the Ladakh range, has cut its bed to a low level on the Tibetan plateau, the fall in this part of its course being hardly more than three feet in a mile; across the Himalaya it has a remarkably equal and comparatively gentle fall.

The eastern end of the Himalayan chain is supposed to have begun to rise earlier than the western. This supposition derives support from the fact that, so far as the southern flank is concerned, Eocene deposits with nummlites are restricted to the western half of the range. Also suggestive of an earlier rise in the east is the swinging round of outcrops of Himalayan rocks at the western end of the range in Kashmir. On the assumption that the Karakoram was the site of a more or less separate but co-ordinate elevation, the general altitude today of the western portion of the Himalaya is also notably less than that further east in spite of the greater rainfall which now visits the eastern portion. The western divergence of the Lesser Himalaya as branches from the Great Himalaya of the Punjab also seems to support the idea that elevation commenced earlier and maintained its lead in the more easterly half of the chain.

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[163] De Terra, on the other hand, suggests that in eastern Zanskar, during the younger Tertiary period, the drainage, including that of the Indus, originally flowed eastwards, and that the source of the Indus may have been in the head-waters region of the Hunza and Gilgit rivers near where the Karakoram bends westwards to merge with Hindu Kush (Geogr. Rev. Vol 24. No. 1, 39-40 (1934). Lydekker also suggested that the upper Indus originally flowed south-eastwards and was at one time continuous with the Tsangpo, but the evidence on which this suggestion is based is somewhat obscure (Mem. 22, 199 (1883).

[164] See Burrard and Hayden, "A sketch of the Geography and Geology of the Himalaya Mountains and Tibet", 171 (1907).

This would have initiated in early Tertiary times, not only the "Indobrahm" line, but also another line of drainage in the same direction on the Tibetan side. In this connection, Middlemiss points out that there is no alternation among the Tertiaries of the Himalayan foot-hills except on a negligible scale. "The whole set of deposits is steadily evolving in one direction", and we find is passing westwards, especially when we leave the Himalayan area and pass on to the Salt Range, the Sulaiman range and the hills of Baluchistan and Sind, that marine strata increase in thickness and encroach into higher member of the Tertiary system—"a fact which indicates that the wave of elevation took place from the east to the west, whereby the sea was driven in that direction, and esturaine and fluviatile conditions supervened".[165] The argument in favour of a longitudinal river, however, derives only a limited support from Middlemiss' views since his remarks would appear to apply only to country including and to the west of the United Provinces.

The two hypotheses of single westward-flowing rivers flanking the Himalaya throughout its length, one on the Indian and one on the Tibetan side, mutually support each other, and are strengthened by the parallelism between the histories of these two hydrographic lines. They both appear to have supplanted marine gulfs or branches of a single gulf at the same period; both seem to have been the result of the Himalayan movement, to which their courses are at right angles; and in both cases the eastern half of the stream, or a part thereof, is presumed to have had its direction completely reversed by capture on the part of an invading river.

In the case of the Tibetan river, we again have an alternative view, viz., that the effect of the Aravalli line of folding persisted to the northern as well as the southern flank of the Himalaya. According to this idea, the peculiar mountain knot on which the Manasarowar Lakes are situated has always been, as it is now, the watershed between the westward Indus drainage and the eastward Tsangpo drainage. If this be so, it again seems strange that the Aravalli folding has had so little effect on the Himalayan chain itself. The whole problem must be left for further work to decide. Its solution, and especially of that part concerning the river on the Indian side of the chain, would be considerably advanced were it possible to prove the date on which the barrier between the Rajmahal and Garo hills was breached; if the breach took place before the formation of the Punjab Eocene gulf, there would be no reason to suppose that the drainage of Assam ever found an outlet other than that across the gap into the Bay of Bengal. The life history of these rivers is a question of the greatest interest and importance and, for that reason, despite the unsolved nature of the problem, has been presented at some length.

Whether or not it ever extended back as far as Assam, the Siwalik river must have flowed along the foot of the Punjab Himalaya, where it was reduced by the piecemeal capture of the portion lying between

[165] Mem. 24, pt. 2, 113 (1891).

the Jumna and the Jhelum by its own tributaries, the Jhelum, the Chenab, the Ravi, the Beas, the Sutlej and the Ghaggar. Each of these tributaries now occupies a wide valley well below the level of the plain. The capture took place in post-Siwalik times and is probably quite recent. It may have been initiated by synclines produced by the earth movement from the northwest. Along these synclines the tributaries named cut their way back across the plains of the Punjab in a northeasterly direction, and captured various portions of the parent river. Whatever way have been the precise order in which these captures were effected, the Ghaggar must have become the final channel of the parent river. The only relic of the old Siwalik river in the upper Punjab is the Sohan of the Potwar, a stream of puny proportions in comparison with the thickness of the Tertiary and Pleistocene fluviatile sediments through which it flows.

The anastomosis of these Punjab rivers is and probably has been a fluctuating factor, but their present parallelism and the general equality of their distances apart suggest that their number was five or perhaps six ; four of them remain, one is a dry channel and, if a sixth ever existed farther south, no trace of it has been recorded. The upper Jhelum has the appearance of having been beheaded by the Chenab, and of having lost the importance commensurate with the size of its valley. The Tibetan river may have been captured by a tributary of the Siwalik river, now the Attock part of the Indus, which cut back into Kashmir.

The ancient geography of the Punjab is far better known than that of most parts of India, partly because the civilisation of the northwest is older than that of other parts of the country, but still more because of the descriptions given by Greek writers of the Indian campaigns of Alexander the Great. It is consequently possible to form some idea of the principal alterations which have taken place during the last 2,000 years in the courses of the chief Punjab rivers. Alexander, however, never penetrated to the eastward beyond the land of the five rivers, and we have only vague tradition to support any effort to reconstruct the behaviour of the Indus and Ganges tributaries in the neighbourhood of the watershed between those two main rivers, where important changes have in all probability taken place since the dawn of history.

If we concede the gradual displacement of the Indus drainage by that of the Ganges, we may regard the capture of the Jumna as the latest stage in the struggle, for the Jumna, although a Himalayan stream, is a right-bank tributary joining the Ganges at Allahabad. The present upper Jumna and the Ghaggar (or Saraswati) formed at one time a single continuous river, which probably received the Sutlej also ; the course of this old channel can stil be traced across Rajputana, Bhawalpur and Sind, where it is variously known as the Ghaggar, Hakra or Wandan, to the Indus. The persistence of this river till historic times would, as noticed by James Ferguson, [166] account for the

[166] Q.J.G.S., 19, 348 (1863) ; R. D. Oldham, "Probable changes in the Geography of the Punjab and its Rivers", (J.A.S.B., 55, pt. 2, No. 4, 322 (1886).

old Vedic tradition that the Saraswati was the "chief and purest of rivers flowing from the mountains to the sea." This important river is known to have carried a powerful stream from the eighth till, at any rate, the sixteenth century. After the Ganges captured the eastern branch of its head-waters by means of the lower Jumna, and the old Beas captured the western branch. (i.e., the Sutlej), the Saraswati dwindled to a small stream which soon lost itself in the desert of Bahawalpur and Sind, the greater part of its channel remaining as the dry Ghaggar or Hakra; the population on the banks of the latter is said to have migrated to the Indus valley in consequence.[167] The water which thence forward flowed along the bed of the Puran to Cutch came from an affluent of the Indus and no longer from the old Hakra channel and Eastern Nara. This capture within the historic period is no doubt responsible for the Hindu legend that it is the Saraswati which joins the Ganges at Prayag Allahabad.[168] Such a capture in historic times i.e., after the various streams had received names, would account for the fact that the Jumna is today looked upon as a tributary and not the main Ganges river. Whether there will be any further invasion of the Indus basin by the Ganges drainage is an interesting matter for speculation; there is no intervening rock barrier to prevent it, the watershed between the two river systems being a scarcely perceptible rise in the plains. The capture of the Jumna shows at least that the Ganges still has an advantage in youth and vigour over the rivers of the present Indus system, and it seems not unlikely that, if not artificially controlled, it will be able to cut back farther north-westwards along the trough—especially if the latter is still being deepend—and make further captures.

There is historical evidence which makes it probable that the Sutlej and the Beas followed separate courses not very long ago. The Mohammedan histories of the 11th. and 12th. centuries and the Hindu writers of Jaisalmer employ the term "Biyah" for the combined Sutlej and Beas, now known as the Sutlej. From this, Oldham surmises that the rivers must have received their actual names at a period when the Sutlej did not join the Beas but pursued an independent course, and that it entered the Beas probably not much before the 11th century;[169] *vide* an interesting but anonymous article, understood to be from the pen of Surgeon-Major C. F. Oldham.[170] It very probably joined the Ghaggar before it was captured by a tributary of the Beas. This old beas channel did not coincide precisely with the river now lying between Sultanpur and Jalalpur and regarded as the lower Sutlej but, as late as 1245 A.D. followed a course which can still be traced past Dilalpur to

[167] The Sutlej seems to have flowed along the Ghaggar channel more than once; about 1593 it is said to have joined the Beas but left it some time later for the Ghaggar, which it finally left for the Beas again in 1796.

[168] Man. 2nd Edit. 450 (1893). The name, Saraswati, is still given to the upper part of the Ghaggar, rising in the state of Sirmur within the Himalaya.

[169] Man. 2nd Edit, 450 (1893).

[170] Calcutta Review, Vol. 59, pp. 1-29 (1874); also J.A.S.B., 55, pt. 2, No. 4, 322-343 (1886).

Shujabad. At this time the Jhelum, Chenab and Ravi met to the north-east of Multan, flowed to the east of that city and joined the Beas near Ghuzadbad. By 1397 the Chenab had changed its course and was flowing west of Multan as it does now, but the Ravi continued for some time to flow east and south of Multan ; even now, in times of high flood water, it finds its way to Multan along this old Ravi channel, which dates back as far at least as 800 A.D.

It is highly probable that the Irrawaddy, by way of its chief tributary, the Chindwin, was at one time continuous with the Tsangpo, which is now known to be the upper waters of the Brahmaputra. The Tsangpo was then shorter than it is now and did not reach so far westwards. Until it was shown to be otherwise, the old Chinese surveyors believed that the Tsangpo of Tibet still flowed into the Irrawaddy,[171] but this, of course, is no proof that it did so within historic times. The Irrawadian sediments of Burma appear to have been deposited by a much larger river than the present main water artery of the country, and may well belong to this old Tsangpo-Chindwin-Irrawaddy which discharged itself into the Pegu gulf ; the thickness and width of the Irrawadian belt in the Chindwin valley especially is quite incommensurate with the present size of this river. The Tsangpo-Chindwin-Irrawaddy river may have been beheaded by an old Assamese river flowing south-westwards between the Shillong plateau and the Naga Hills, a relic of which remains today as the Meghna. Here again, from the size of the Siwalik deposits in the railway hill-section of Assam, this old Meghna appears to have been a river of some magnitude and may well have derived its importance from the capture of the Tsangpo. Whether the Meghna was an intermediary or not, the " Indobrahm "—or Brahmaputra, as it may then have become—eventually captured the Tsangpo. The Kapili tributary of the Brahmaputra seems to have cut back at some time between the Mikir Hills and the Shillong plateau and captured a part of the Meghna. The Kali Gandak seems to have captured the upper part of the Tibetan river,—at that time flowing westwards,—and to have thus been enabled to scoop out the extraordinary depression of the Photu Pass, which is only 250 feet higher than the Tsangpo plains. The Sutlej appears to have effected a similar capture, part of the captured river still existing as the uppermost reaches of the Sutlej.

It is difficult to assign dates—even relative dates—to the changes discussed in this section. It was probably before the end of the Siwalik period when the Attock tributary joining the main river near Makhad cut back into the Ladakh valley. That portion of the modern Indus which runs just below Bunji, at any rate, is of no very recent construction, as shown by the colossal depth of its gorge—nearly 17,000 feet. The steepness and narrowness of this gorge are witnesses to its immaturity, but its immense depth compared with the hardness of its rocks places a limit to our conception of its youth.

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[171] Burrard and Hayden, " A sketch of the Geography & Geology of the Himalaya Mountains and Tibet", 157 (1907).

The Attock tributary subsequently formed part of the longest line of waterway and, according to modern convention, now bears the name of the main river, the Indus.

In a country of such hoary and carefully preserved tradition as India, geographical names have a peculiar interest and possible importance. For example, it has been shown that part of the old Siwalik river course is now occupied by the Sohan, draining the Potwar and flowing westwards into the Indus. It is, therefore, interesting to find another river of today, occupying another, but distinct, portion of the old Siwalik river course and called by the same name. Sohan ; this river now flows into the Sutlej between the Siwalik hills and the Solasinghi range, and in a *southeasterly* direction, *i.e.*, in a direction opposite to that of the old Siwalik river. Still more interesting it is to note that, in line with this Sohan to the northwest and separated from it by an insignificant divide near Dangoh, is another small stream, also called the Sohan and flowing *north-westwards* into the Beas. One is tempted to deduce that, within historic times the Punjab portion of the "Indobrahm" was still in existence, flowing along the base of the Simla hills across the Potwar into the Indus, and known as the Sohan.

Oldham has remarked on the suggestiveness of the fact that, in two cases where rivers have taken a different course, namely, the Saraswati into the Ganges instead of to the Indus, and the lower Brahmaputra from its old Mymensingh course to a more westerly one, the new channel formed has been termed the Jamuna or Jumna. There is another Jamuna in Assam flowing westwards through the southern angle of the Mikir Hills into the Kapili river, a tributary of the Brahmaputra. Its history is not quite clear, but the Kapili (or Kalang, as the main affluent is called) has cut back between the Mikir Hills and the Shillong plateau, past Lumding, and may have captured part of the old reduced Meghna, after which it is possible that the Jamuna cut back further north through a low gap in the Mikir Hills, and snatched the Meghna head-waters from the Kapili. This portion of the old Maghna valley is now drained by the Dhansiri in the reverse direction. Jamna or Jamuna in Sanskrit means "one of twins" (the feminine form since applied to a river), a not inapt name for the alternative course of a stream ; in fact, for a short time, while the capture was being effected, the part being captured would split into two, one part of its waters proceeding down one channel, and the other part down the other—twin rivers with a common origin. On the other hand, it may simply be that the rivers have been named after the sister to the God of Death.

Conditions of deposition in the trough.—A brief review of the conditions which prevailed during the formation of the great trough along the foot of the Himalaya and its continuing ranges will complete the story. The Siwalik sediments are those of a wide plain belonging to a large river of low gradient, a conclusion which is in harmony with the presence of hippopotami, crocodiles, turtles and other aquatic vertebrates of similar habit. The remains of birds such as the pelican and stork bear witness to the presence of large

meres, while the wide plains through which the river and its tributaries meandered supported the ostrich and emu, as well as giraffes and other plains-loving mammals.

While the sediments were accumulating, it is obvious that a gradual and prolonged general subsidence must have kept pace approximately with deposition. This subsidence was accompanied by a certain amount of warping and corrugation caused by the Himalayan movement which must have continued throughout the entire succession from the Eocene to the present day. The total maximum thickness of fluviatile sediment deposited in the trough may be of the order of 40,000 feet though, in consequence of the severe folding which accompanied the earlier sedimentation, no uninterrupted section might ever show more than 20,000 feet. The thickness of the Nimadric sequence has been calculated to be between 20,500 and 23,000 feet, the Murrees averaging about 6,500 feet but reaching a maximum of at least 7,000 feet, and the Siwaliks attaining from 14,000 to 16,000 feet made up of 3,200-4,000 feet of Lower Siwaliks as measured in the Potwar, 5,500-6,000 feet of Middle Siwaliks as measured in the same section, and 4,000-6,000 feet of Upper Siwaliks as measured between Jalalpur and Kotal Kund. No definite figures concerning the maximum thickness of the Indo-Gangetic Alluvium are available, but from geodetic considerations its thickness is thought to be not much less than that of the Nimadric sequence.

That the bulk of the sedimentary material was derived from the Himalaya and corresponding ranges to the west of the Jhelum is indicated not only by composition of the conglomerate pebbles and sand grains, but also by the thinning out of various stages southwards; such thinning out is well seen in the case of the Kamlials, Chinjis and Nagris of the Potwar. It is true that the Dhok Pathans show a thickening southwards, but this seems to be a slight and inadequate compensation for the thinning of the earlier stages; the latter also thin out westwards from Khaur.[172] In a general way, the effects of the Himalayan movement, intense in the higher parts of the chain, became less so along what is now its southern margin, and decreases thence outwards. The fluviatile sediments, especially the earlier ones, became involved in the folding, and the river was thus thrown little by little farther south. This process was assisted by the great excess of silt brought down by the drainage of the mountainous region to the north over that contributed by the drainage of the land on the Peninsular side. This retreat of the hydrographic line towards the Peninsula was especially well marked in the northwest Punjab, the North-West Frontier and Baluchistan. On its right bank the Siwalik river received young and vigorous tributaries born in the Tertiary era. On its left bank it received tributaries, some of which may have been relics of very ancient rivers which drained the Gondwanaland; possibly the Chambal and its branches and the Son belong to this category.

It is because the Himalayan folding movement accompanied and survived the deposition of the Siwaliks that the latter have, in the

[172] Rec. 65, pt. 1, 121 (1931).

words of Middlemiss, been "won from the oblivion of the plains and added to the achievements of the Himalaya".[178] Were it not for other disturbing factors, the combined results of earth movement and contemporary deposition would have been everywhere a belt of river sediments, decreasing in age and general disturbance with complete regularity from the hills outwards. In a very general way the belt is so constituted. From the Potwar to Garhwal we find along the inner margin the Murree sediments isoclinally overfolded, followed outwards by the various stages of the Siwaliks. This simple scheme, however, has been complicated by thrusting, faulting and corrugation in the river trough. In the Potwar area the rise of the Salt Range, imposed a limit to the southward migration of the river and minimised the overlap of older stages of the Siwalik by the younger ones. Here the unconformity between the Eocene and the Murrees signifies no severe deformation after the withdrawal of the sea; occasionally there is actual truncation of the older beds but, although the Murrees lie on different horizons of the marine beds from place to place, the discordance in dip is imperceptible. In some places, on the other hand, local upheaval on a considerable scale has caused inter-formational erosion and unconformity such as that which accounts for the apparently complete absence of the Middle Siwaliks in the Bugti Hills. The same division of the Siwaliks appears to be absent or scantily developed east of the Jhelum but this is partly due to incomplete surveys, and perhaps considerably to the fact that much of the Tertiary succession lies beneath overthrust older rocks. In the Simla area, these older rocks have been pushed southwards for some 25 miles over the Murrees and Eocene, so that the total width of the Tertiary belt in the Simla section is probably as great as it is in the mandi area farther northwest. In parts of the Potwar, conglomerates assigned to the uppermost Siwalik stage lie quite unconformably upon Middle Siwalik beds; the latest phases of the orogenic movement have thrown these conglomerates into the highly tilted position they now occupy in many places.

The accumulation of the Nimadric sediments is not likely to have proceeded at a uniform rate, for there are several factors which would have affected the rate of deposition as well as the texture and composition of the beds. The supersession of sandy deposits by argillaceous, such as that seen on passing from the Kamlial to the Chinji, may have resulted from a lull in the elevation of the catchment area due to a temporary cessation or retardation of the folding movement. The same change might have been brought about by the cutting back of the mountain streams into the rocks of more argillaceous composition. Predominantly sandy stages, such as the Kamlial or Nagri, may indicate a more intense phase of folding and a rejuvenation of the tributary drainage. Still more likely is such an increase in the rate of mountain uplift to have been responsible for the great conglomeratic deposits of the uppermost stage. A peculiarity of the Murrees and of the Lower and Middle Siwalik divisions is the small proportion of the coarser forms of silt such as

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[178] Mem. 24, pt. 2, 20 (1890).

conglomerate and grit. It is only at wide intervals that such coarse material is found scattered through many thousands of feet of comparatively fine-grained sediment; as Anderson has remarked, this confirms the conclusion based on other features, that the bulk of the Siwalik beds were spread out over level plains, many miles from the hills or mountains which supplied their materials.[174]

The formation of the coarser detritus such as that found in the Boulder Conglomerate stage may have been due, not only to a vertical rise of the mountainous catchment area, but to the southward thrusts which began to play such a prominent part towards the end of the Siwalik period and brought the sources of sediment nearer to the plains on which they were laid down. The formation of the conglomerate may well have been assisted also by increase in precipitation consequent on the greater elevation of the Himalayan ranges; this increase in precipitation may have been the partial cause of the general decrease in red colouration seen in the Siwalik sequence due to an increasing preponderance of silt derived from the mountains to the north over the more lateritic sediment brought from the south by Peninsular tributaries.

Conditions of today are but a continuation of those that prevailed during later Siwalik times, and the Indus, Ganges and Brahmaputra alluvial deposits are but the immediate successors of the Tertiary. The jungle-covered plains of these great rivers or the single river they have perhaps supplanted, supported in the past an even richer fauna of herbivorous animals than they do today. Locally at any rate there were woods which sheltered monkeys and have left relics of their presence in silicified and carbonised logs. Here and there stagnant swamps encouraged the formation of lignite or coal, but such conditions never seem to have obtained for any length of time or over any extensive area. The pseudo-conglomerates may indicate seasonal desiccation. Actual soil deposits are not definitely recognisable, but the red beds of the Murrees and lower horizons of the Siwaliks may well be redistributed soil brought down chiefly by the streams draining the Peninsula.

Anderson ably summarises our knowledge of the Siwalik climate. "The presence of animals ancestral to the modern giraffe, camel and ostrich, appears in harmony with the idea of moderate precipitation. The mingling of these animals with the numerous species of elephants, with horses, oxen, antelopes, rhinoceros, lizards and other forms, including their carnivorous associates, bears out the conception of a locally forested and locally open country of low relief, under a semi-tropical climate of medium rainfall."[175] As Anderson remarks, the gradual rise of the Himalayan chain was probably the chief factor in the transformation from the aridity which caused the deposition of the Eocene salt to the moderately and increasingly rainy climate of the Siwalik period, the Murree climate being of intermediate character.

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[174] Bull, Geol. Soc. Amer., Vol. 38, 681 (1927).

[175] Bull. Geol. Soc. Amer., Vol. 38, 695-696 (1927).

Earthquakes.—One of the most convincing and striking froms of evidence indicating a continuation of the Himalayan movement is to be seen in the earthquakes which from time to time play such havoc especially in the thickly populated Indo-Gangetic alluvial area with its large cities crowed with important buildings. Earthquakes may result from violent volcanic eruptions as well as from explosive outbursts of gas such as those which seem to have been responsible for the Arakan quake of 1762, but the vast majority of earthquakes in India appear to be of tectonic origin and caused by abrupt jerky movement of rocks over other rocks along fault-planes. The siesmic centres of a large number of Indian earthquakes have been found to lie along the belt of faulting which characterises the southern flank of the Himalaya, and it is probable that these convulsions are due to a continuation of the N.-S. earth movement which is still pushing the rocks southwards along some of the later thrust-planes.

This impulsion of a mountain mass up the thrust-planes takes place for the most part in a succession of minute harmless movements imperceptible to human faculties though in many cases recognisable by delicate seismographs. If the term earthquake be applied to such minute shocks, whether recorded or unrecorded by a seismograph, we may regard earthquakes as being part of the normal and inevitable life history of this mountain chain. This continuous and imperceptible movement, in other words, is just one among the other ordinary phenomena which accompany the attrition of such a mountainous belt by natural agencies. Between the years 1885 and 1892 no fewer than 8,331 earthquakes were recorded in Japan, an average of nearly 23 a week. Such minute shocks are probably just as frequent proportionally in the Himalaya, and are, we must suppose, numerous enough to diminish largely the frequency of the destructive convulsions which startle the country from time to time. The latter may be attributable to some obstacle at certain parts of the fault—some obstructive friction which accumulates until it has to yield in a jerk of appreciable intensity.[176] In this connection the intensely hot weather, which is the traditional forerunner of an earthquake may not be entirely unconnected with the cause of its violence. It is at any rate conceivable that the gradual harmless smooth movement of normal times is effected along lubricant surfaces such as those of moist clay, and that any desiccation of these surfaces through excessive evaporation might result in obstructive friction sufficient to cause a temporary halt in the movement and in accumulation of pressure which would be suddenly relieved by a jerk forward along the plane. Another phenomenon which might possibly check for a time any rock movement along a thrust-plane is the incipient warping of the plane itself ; ultimately, the plication of such a plane would prohibit any further movement along it at all. Such a folded obsolete thrust-plane would presumably be replaced by a new plane of fracture in the near neighbourhood. Opposed to the above general idea of the cause of Himalayan earthquakes is the fact that the impulse of an earthquake appears to origanate from any of the

[176] Pascoe, Journ. Roy. Soc. Arts. 82, 583 (1934).

Himalayan thrust-planes; in the Kangra disturbance of 1950 this depth is estimated to have been between 16 to 20 miles. What this precisely means, however, is not yet known. A fall in barometric pressure is an event which might encourage the production of an earthquake, the reduction in pressure being perhaps sufficient to set off a quake already imminent.

In our consideration of the Himalaya as a corrugated and disturbed belt made up of a continental margin and the sediments lying off its coast, it has been assumed that, at the syntactical points which terminate the chain, earth movement has been brought more or less to a standstill. The bulge between these two limits appears to be largely due to an actual advance of the mountain chain along the faults. If this be correct, we should expect to find seismic centres more frequent, and the shocks they belong to more violent, in the central more advanced portion of the mountain arc and absent or rare near its extremities. A map showing the distribution of Indian earthquakes of the nineteenth and twentieth centuries supports this conclusion. No epicentre has been recorded anywhere near the eastern end of the Himalaya, and only one—of a "slight shock—near the western";[177] most of the epicentres occur along the bulging portion of the chain. The geological map of the Punjab shows two curious embayments of the trace of one of the most prominent of the thrust-faults—that commonly alluded to as the "Great Boundary Fault"—one near Kangra and Dharamsala and the other near Mussoorie. These embayments might give the impression, in each case, of a lagging behind of the old rock above the fault, as if they had met with some local impediment to their advance. According to Auden, however, the former of the two re-entrants is a purely erosional feature; there is little indication of a packing up or virgation of folds which, on the contrary, preserve a general N.W.-S.E. trend and are abruptly truncated by the re-entrant.[178]

Occasionally there are signs on the surface of the movement of the rocks along the faults. Such evidence is uncommon for the reason that any relative shifting among the rocks is almost immediately hidden beneath falling debris or rapidly obliterated by denudation. This shifting is, of course, not always confined to a single fault but may be distributed among a series of parallel or échelonned fractures. As an outcome of the Kangra earthquake, Middlemiss records a true rock fissure near Larji, showing perfectly fresh surfaces and lying along a line of faulting; it did not appear to be the result of gravity since it dipped into the hill-side, but suggested fresh movement along an old fault. Fissuring in the ground is a frequent consequence of an earthquake and might be expected as a tensional effect following

[177] Since this chapter was written, Coulson has published an account of an earthquake having an epicentre somewhere in the Great Pamir, N.N.W. of Gilgit and apparently quite close to the syntactical bend of the country rocks, and occurring in November, 1939. The focal depth was estimated to be of the order of 200 kilometers and the maximum intensity was registered as 8 in a scheme ranging from 1 to 10, and occurred at Gilgit (Rec. 75, Prof. Pap. No. 12(1940).

[178] Mem. 73, 145 (1939).

a relieved compression. Most of the fissures are superficial effects, and many of them appear to be the result merely of the shaking and warping. Some of them look formidable enough, but as a rule they are of no great depth and are typical of alluvial tracts; they are, however, sometimes quite numerous in the hills. The formation of fissures was especially widespread in the Shillong earthquake of 1897, but the phenomenon has been recorded in connection with the Cachar earthquake of 1869, the Kangra earthquake of 1905, the Burma earthquake of 1912, the Srimangal earthquake of 1918 and the Bihar-Nepal earthquake of 1934. The alternation of compression and tension in an earthquake is illustrated by the effect on a railway line; portions of the line may show buckling due obviously to compression, while breaks in the line elsewhere indicate tension. Undulations of the ground are often felt or seen, and were recorded in the shocks of 1897 and 1905 and in the Burma earthquake of 1912. In flat ground small, shallow, saucer-like hollows are sometimes left behind by earthquakes, accompanied or not by small low mounds; some of the hollows appear to be the result of sand-spouting.[179]

A severe earthquake is for months afterwards followed by innumerable after-shocks which gradually diminish in number; during the immediately succeeding twenty-four hours they may be numbered in hundreds. As might be expected, these after-shocks do not all originate from the same point, but from many points in the vicinity of the main seismic centre. At all these points or secondary epicentres, subordinate strains set up by the main shock evidently require early adjustment. It is not easy to decide what to classify as after-shocks of a serious quake, and what as ordinary minute normal advances. The seismograph in Simla continued to record what have been called after-shocks of the great Kangra earthquake of the fourth April, 1905, till the end of 1907; with that year compartive quiescence set in and the few shocks recorded began more and more to lose the aspect of genuine after-shocks.

Not the least terrifying consequences of a great earthquake in the Himalaya are the landslides which sweep down like avalanches on villages and towns below. These are not always confined to loose soilcap and debris lying on the hill-slopes, but at times include portions of the country rock which split off leaving fresh bare scars. Not only are these rock falls an accompaniment of the shock itself, but a large number of them, some of considerable magnitude, follow at intervals for weeks afterwards, for the hill-sides, fissured and weakened by the shake, are at the mercy of any serious rain-storm. These storms are naturally aided in their destructive work by the numerous after-shocks. In a hilly region, especially one of narrow gorges, the landslides, caused directly or indirectly by an earthquake, frequently form unstable dams in the streams at the bottom, ponding back the water and producing large temporary lakes, the waters of which, when the dam bursts, sweep down, carrying all before them. Should two such lakes so form in different parts of the same stream and the upper dam yield first, the force of the water thus liberated

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[179] Murray-Stuart, Mem. 46, pt. 1, 9, 14 (1926).

is almost certain to burst the lower dam, and the double flood pours down the rest of the valley. Earthquake floods, however, are not all due to landslides; the most widespread of them are, in fact, produced in a less violent way, especially in flatter types of country. They are the result of the rise of river beds, or of subsidence below flood-level of the high land bordering them. In this way large areas of lower-lying land are inundated and crops and livestock destroyed. Deviation in ordinary drainage channels is also caused by the deposition of silt in unusual amounts and in unusual places. The eruption of sand from fissures is a local effect caused by the temporary momentum imparted to a water-bearing stratum underlying the alluvium; fissures in the latter allow the sand and water to issue in a kind of spout.

It might well be expected that the strain which has accumulated along a fault belt is not always completely relieved by an earthquake but persists at certain points where the obstacle to earth movement was not completely overcome. In the 1905 catastrophe, for example, while the Kangra and Dharamsala area constituted one epicentre and the Dehra Dun and Mussoorie area another, Simla, a hill-station between the two areas, was only midly affected by the disturbance. Warnings were, in fact, issued to the effect that the rocks beneath Simla might be in a state of unrelieved strain. That no subsequent shock has yet eventuated at Simla may be due to the dissipation of the strain by numberless infinitesimal movements of a harmless nature spread over a period of years. It would thus seem impossible to foretell an earthquake with any precision, even if it were possible to indicate by electrical or other experiments that a state of strain existed in any section of a fault-belt, it would be quite impossible to predict when the shock would be likely to occur, or to say whether or not the strain would be dissipated by innumerable minute and gentle movements.

Preliminary shocks of a minor nature usually occur a few seconds before the main quake. These are thought to be the result of waves through the deeper parts of the earth's crust, travelling faster than the surface waves which cause the damage. The warning they give has been effectual in isolated instances but, generally speaking, is far too short to be of practical value; it is discounted also by the ignorance of all concerned as to whether these tremors are no more than ordinary small adjustments or are the preliminaries to some great cataclysm.

Earthquake shocks of any appreciable intensity are almost entirely confined, so far as the location of their epicentres is concerned, to the Extra-Peninsular parts of India, and are not infrequent in Baluchistan and Burma as well as the Himalaya. The only exception is the Shillong plateau which, although believed to form part of the Peninsular region, is a particularly unstable portion thereof. Its instability may be due to its position within the sharp angle made by the Himalayan and Burmese wave fronts, and in this way a result of Extra-Peninsular conditions. One is tempted to infer that the absence of reports of disturbances of any intensity having their epicentres

located in the Bhutan, Aka or Dafla hills on the one side, or in the Manipur or Lushai hills on the other, is largely due to translation of the disturbance to the intervening Shillong plateau where, as would be expected, the dislocations are complicated and consist to a large extent of shearing and tear-faulting. Too few data regarding seismic disturbances in the wild hill country north of the Brahmaputra or along the Assam-Burma frontier are available to make it possible to promote such a suggestion to a definite statement.

Scarcely a week passes without a perceptible tremor being felt at Shillong and other places on the plateau. The Shillong earthquake of 1897, which seems to have been a very complicated one, is thought to have been caused in the usual way by movement along a thrust-plane, but its effect was intensified by new faults of normal character. The horizontal width of the thrust-faulting along which movement is believed to have taken place is estimated to have been about 200 miles. One of the N.-S. more or less normal faults, wherever visible, was traced for twelve miles and probably extended much farther; it showed a maximum throw of 35 feet, a relative displacement which alone would have been sufficient to account for a very severe earthquake. A large block of granite which happened to lie across the line of this fault was overturned thereby. The normal faulting in this earthquake was not all in the same direction. For days after the main shock the earth in this region never came to rest but was in a constant state of gentle tremor, interrupted now and then by severer shocks. Two of the latter, in the words of R. D. Oldham, were severe enough to have caused great destruction in the central area, had there been anything left to destory, and were felt as far as Calcutta. The main shock of this disturbance did considerable damage in Calcutta. The same writer describing the appearance of the southern face of the Garo and Khasia hills as viewed from the deck of a steamer sailing up to Sylhet, says; " the high sandstone hills facing the plains of western Sylhet, usually forest-clad from crest to foot, were stripped bare, and the white sandstone shone clear in the sun in an apparently unbroken stretch of about 20 miles in length from west to east. Beyond this the landslips, though still large and conspicuous, grew gradually fewer ".[180] By the same earthquake, the hill-sides of the small Mahadeo valley were stripped bare from top to bottom. The innumerable small earthquakes of the Shillong plateau appear to be due to tiny jerks along the N.-S. tear faults.[181]

Earthquakes having their origin in the Peninsular tract have been of neligible importance. Mention has already been made of the faulting—probably of a normal character—along or close to the west coast; and relics of the sunken portion of the old continent have recently been found beneath the Arabian Sea. Possibly the few slight tremors felt occasionally along the Malabar coast and particularly in Travancore[182] are the dying phases of this dislocation.

[180] Mem. 29, 115 (1899).
[181] Rec. 72, pt. 1, 92 (1937).
[182] Mem. 35, pt. 3, 11 (1904).

The suggestion that the denudation of the Himalaya and the deposition of sediment along the Indo-Gangetic alluvial belt have combined to bring about earthquakes, might invite the accusation of mistaking cause for effect, for the Himalayan folding movement unquestionably came first and was one of the causes of the denudation to which the upraised area has been subjected. At the same time, it would be wrong to ignore the fact that the weight of sediment in the belt of deposition is added to every day at the expense of the weight over the mountainous area, and from common sense it may be inferred that the thrusting of the lightened Himalaya over the weighted alluvial trough is facilitated thereby, and is to some extent a recurring effort towards equilibrium between the hills and the plains. The weight of the Himalaya is being reduced every day, especially during the torrential monsoon rains, only to be restored presumably by the further upthrusting of its rocks along the thrust-planes. The scouring action of torrents and glaciers is at a maximum in a drainage system so young as that of the Himalaya, and anyone who has watched whole hill-sides crumbling away during a rain-storm in the monsoon, or has seen a flood sweeping down on to the plains which its thousands of tons of silt, will have no difficulty in appreciating the lightening effect on the mountainous belt. These changes must be causing slight variation in the heights of Himalayan peaks from decade to decade, though the variation is not likely to be more than a few feet unless the mountain top is visited by some major catastrophe.

Cause of the Himalayan uplift.—The cause of the Himalayan uplift is a subject to which only a brief reference can be made. It is not yet clear whether it is justifiable to speak of the rise of the Himalaya as having been caused by folding, or the folding as having resulted from the rise of the mountain chain ; it is for the present safer to regard the one as accompanying the other, and to speak of the thrusting and reversed faulting as accompanying rather than resulting from isostatic readjustment which tends to balance the transfer of sediment from the Himalaya to the plains.

A theory which received a good deal of attention during the latter half of the last century is one which ascribed the upheaval of the Himalayan chain and other mountain systems of the world to an isostatic readjustment of the earth's crust. Briefly, omitting complications, the case may be put as follows : starting with the well known fact that a plumb-line in close proximity to a mountain range is diverted slightly away from the vertical in the direction of the range, we come to another fact, not quite so well known, viz., that in the case of the Himalaya as well as in the case of the mountains of the United States of America, this deflection of the plumb-line from the vertical is in very many places much less than the theoretical value based on the mass, density and distance of the hills. As early as 1855 it was suggested by George Airy[188] that the anomaly was due to the lower density of the rocks in and under the hills, an idea which was subsequently adopted and modified by Archdeacon Pratt.

[188] Phil. Trans. Roy. Soc., Vol. 145, p. 101 (1885).

In 1889 the theory of isostasy was enunciated by C. E. Dutton[184] and taken up by Hayford, Bowie and other American geodesists. According to this, if the heterogeneous material composing the earth were equably disposed in concentric layers about its centre, there would be equilibrium and no tendency towards a rearrangement. The Earth's crust, however, is not so symmetrically constituted. The stresses caused by gravity tend to produce such a symmetrical disposition of the variously dense materials, but is prevented from doing so fully by the viscosity of the materials, which is considerable near the surface. The readjustment effected by gravity will be thus imperfect. In the words of Hayford:

" In the partial rearrangement some stresses will remain, different portions of the same horizontal stratum may have somewhat different densities, and the actual surface of the earth will be a slight departure from the ellipsoid of revolution in the sense that above each region of deficient density there will be a bulge or bump on the ellipsoid, and above each region of excessive density there will be a hollow, relatively speaking. The bumps on this supposed earth will be the mountains, the plateaux, the continents; and the hollows will be the oceans. The excess of material represented by that portion of the continent which is above sea-level will be compensated for by a defect of density in the underlying material. The continents will be floated, so to speak, because they are composed of relatively light material; and similarly, the floor of the ocean will, on this supposed earth, be depressed because it is composed of unusually dense material. This particular condition of approximate equilibrium has been given the name isostasy. The compensation of the excess of matter at the surface (continents) by the defect of density below, and of surface defect of matter (oceans) by excess of density below, may be called the isostatic compensation ".

It was then assumed that there was a certain depth below which isostatic compensation is complete. At and below this " depth of compensation " the condition as to stress of any element of mass was believed to be isostatic. At and below this depth any element of mass was believed to be subject to equal pressure from all directions as if it were a portion of perfect fluid. Above this depth, on the other hand, each element of mass was considered to be subject in general to different pressures in different directions—to stresses which tend to distort it and move it.[185]

It was then found that, on the assumption that isostatic compensation is complete at a depth of 113·7 kilometres (subsequently corrected to 122 kms.), the anomalies between the observed and computed values for the plumb-line deflection became comparatively insignificant throughout the United States. The same assumption however, produced no such result in India, where calculations were complicated by another peculiarity, viz., the rapidity with which the plumb line approached the vertical when receding from the Himalaya.

[184] Bull. Phil. Soc. Wash., Vol. 2, 51.
[185] The figure of the Earth and Isostasy, p. 66, (1909).

It was suggested by Sidney Burrard that, in addition to a partial compensation due to the coincidence of the Himalaya with a belt of low density, there is a belt of excessive density ("an invisible chain of excessive density"), parallel to the Himalaya, underlying the plains of India about 150 miles from the foot of the mountains, passing through Jubbulpore, and corresponding with some closeness to the Satpura protaxis. The presence of this belt of high density, whose parallelism to the Himalaya suggests unity of origin, has been confirmed by the results of pendulum experiments.[186]

Allowing for the effect of this "Hidden Range", as it was called, it was found that, unlike the experience in the United States, there was no constant depth of compensation at which all anomalies disappeared. Burrard attempted to explain this by assuming that the Indo-Gangetic area is not merely a simple alluvium-filled trough shallow on the south and southwest and deepening steadily towards the mountain foot, but an immense rift stretching along the foot of and beneath the Himalaya and filled with alluvial deposits to a depth of nearly 10 miles; in many of its details this idea conflicted too much with geological evidence and conceptions to be acceptable. Another cogent suggestion is that the Himalaya is perhaps, not in such complete isostatic equillibrium as the United States.

Hayden's contribution to the discussion showed that by assuming the average depth of compensation in the Himalaya region to be 329·8 kms., the discrepancies between observed and computed plumb-line deflection and gravity-strength figures were less than they were on the assumption that this average depth was considerably greater or less. At the same time the local variation from this figure was in many cases very large, e.g., under Dehra Dun and Mussoorie the most suitable figure proved to be 250 kms., below Murree it was 160 kms., under Lambatch 300 kms., below Kurseong perhaps 450 kms., and below Birond a little more than 600 kms. Incidentally the deflection of the plumb-line was found to increase generally with increase of longitude, i.e., from west to east. In the stable Indian Peninsula still greater variation was found, the depth of compensation working out to about 600 kms. in the west, about 329·8 kms. in the east, and zero in the south.[187]

R. D. Oldham's interpretation of the gravity anomalies led him to make the following deductions concerning the Indo-Gangetic trough: (i) that a rock barrier or floor extends at no great depth below the surface of the alluvium from the Peninsular tract to the Shillong plateau in the east and to the Salt Range in the west; (ii) that the depth of the alluvium along the edge of the Himalaya is of the order of 15,000 to 20,000 feet near the northern border of the plain; (iii) that from the maximum depth of the alluvium, which occurs at a distance of from 10 to 30 miles from the northern edge of the plain, the floor slopes upwards with a moderately uniform slope to the southern limit[188] and (iv) that the portion of the floor in a

[186] Rec. 43, 144 (1913).
[187] Rec. 43, 159 (1913).
[188] Hayden's calculations made the slope a little more than 2°.

line with the Aravalli Range shows a local rise.[189] With regard to (iii), Hayden deduced that the depression is separated from the Himalaya by a steep wall resulting from the series of reversed faults which brought up the older rocks over the younger.

Finally, a recent paper by E. A. Glennie[190] throws doubt on many of the principles of isostasy and is at the same time reminiscent of Hayden's suggestion that the depth of compensation is not constant but is an uneven irregular surface. The presence of Burrard's "Hidden Range" across the northern part of the Penninsula is supported by Glennie who claims, however, that the theory of isostasy is not upheld by gravity and deflection results in India (p. 1). This author starts with Harold Jeffrey's hypothesis that the earth's crust is made up of an outer granitic layer (10 kms. thick), overlying a layer of tachylitic nature (10 kms. thick) which in turn rests upon an inner layer of dunite.[191] The dunite (Specific gravity 3·29—3·32) is considered to be plastic and capable of being pressed aside by any downward movement of the two more rigid layers. The gravity anomalies found over sedimentary rocks are attributed by Glennie to a down-warping or down-faulting of the earth's crust, the base of the "tachylitic layer" (Sp. Gr. 2·851) descending below the normal top of the dunite layer and the bottom of the granite layer (Sp. Gr. 2.67) sinking in conformity. This down-wraping of the granite and tacylitic layers, which are assumed to descend without change of thickness, is compensated by a rise in an adjacent area of the dunite layer pushing up with it the two overlying layers. Over the depression there would result a negative anomaly, due to the reduction of normal density caused by the sinking of the granitic layer into the tachylite and of the tachylite into the dunite. Over the raised area would occur positive anomalies, for converse reasons, balancing the negative anomalies over the depressed areas. Denudation of the raised area would provide sediments to fill up the depressed area. The gradual rise of the Hidden Range would have brought the tachylite nearer and nearer to the surface, until the rigidity of the overlying granitic layer broke down, the result being the outpouring of the Deccan Trap. While the Hidden Range was being formed, the Himalayan region was occupied by the broad, shallow depression of the Tethys geosyncline. The continued and excessive sinking of this geosyncline is presumed to have caused crustal weakness and a rapid deepening and narrowing of the trough. The sediments are imagined to have been folded as a result of this narrowing, and surplus sedimentary matter to have folded up above the trough to produce the Himalayan chain.

Although the idea of a constant depth of isostatic compensation appears to be inapplicable to the Himalayan region, it does not necessitate the complete rejection of the doctrine of isostasy. In the course of ages, immense quantities of material have been eroded

[189] Mem. 42, pt. 2, 199 (1917); see also Rec. 55, pt. 1, 78 (1923); Major Cowie, Surv. Ind. Prof. Paper, No. 18, (1921).

[190] Surv. Ind. Prof. Paper No. 27 (1932).

[191] See H. Jeffreys, "The Earth", 2nd Edit. 116 (1929).

from the Himalaya and deposited along the plains below or in the sea. Isostasy requires that an equivalent mass be abstracted from the vicinity of the trough or delta and returned to the area of erosion; this, it is claimed, could only be accomplished by a subterranean flow, forming part of an extremely slow process. In fact, it is difficult to conceive how the immense mass of the Himalaya could have been uplifted alongside the Indo-Gangetic trough, without the aid of some appreciable difference in the density between those two crustal belts. In such a concept, the lighter rocks below the hills would have been able to respond to the centrifugal force of the rotating earth more than the heavier alluvial belts; we should have to imagine them to be flung out from the surface and yielding at the same time to lateral plicatory forces and thrusts. There is even a vague suggestion that the Tibetan plateau, 16,000 feet above sea-level, represents equilibrium from the isostatic point of view, for Wager has calculated that in the Everest area, between the altitudes of 27° 30′ and 28°, the volume of land above 16,000 feet is almost equal to the volume of the valleys below that altitude.[192]

Adherents of the Continental Drift theory find suggestive confirmation in the fact that the great mountain systems of Asia (Himalaya), Southern Europe (Alps) and South America (Andes) occur along the outward margin of what they regard as drifted fragments of the broken Gondwanaland. The possible relationship between gravity anomalies and the union across upraised marine sediments of two separate continental masses is a subject which might repay investigation. The folding and thrusting in the Himalayan chain connote an immense reduction in the original width of rock outcrop, and this must have involved a great northward drift of the Peninsular portion of the country. In the Sub-Himalaya, where the folding has been least severe, Middlemiss has estimated in one case a contraction in width of outcrop of 8 miles in a distance of 19 miles. A recent computation by P. Evans arrives at a figure of 200 miles for the total contraction in the Tertiary rocks of Assam, as a result of close packing caused by small thrusts. The contraction in the higher parts of the Himalayan mountains must have been on a vastly greater scale. No accurate mathematical estimate of what this has been will be possible till the thrusting and folding have been worked out across a complete section.

As a corollary to the conception of the geodesists, Wager has raised the query as to whether the rise of the Himalaya along the edge of the Tibetan plateau should not be regarded as an uplift to compensate for the denudation effected by rivers into the plateau margin.[193] The more deeply indented the plateau margin, the loftier should be the local uplift. This idea is not without some apparent support from physiographical facts, and it is at least suggestive that where the Himalayan region has been most deeply and widely invaded—as it has been by the Tista river system— the range in the neighbourhood soars to its maximum height in Mount Everest and

[192] Rutledge, "Everest 1933," 329 (1934).
[193] "Nature", Vol. 132, p. 28 (1933).

to a not much less imposing altitude in Kinchinjunga. Disregarding the mechanism of folding and thrusting by which this was accomplished, we might regard the extra elevation of the Great Himalaya here to be a compensation for the enormous excavation of the Tista valley. If there be any truth in the suggestion, we should be better able to distinguish between cause and effect; we should have to look up on the extra denudation as the cause of the extra uplift, since the former is undoubtedly a result chiefly of the excessive rainfall due to the gap between the Rajmahal and Garo hills through which the moisture-laden S.S.W. monsoon sweeps unchecked until it meets the Sikkim Himalaya. In the light of the concept put forward by Wager, the study of the longitudinal profile of the Great Himalaya is also suggestive. In the western half, where the great range is almost uncut by gorges, it seldom rises above 20,000 feet; moreover, the only gorge of any size in this practically solid section, the Zoji La, lies beside the peak of Nana (Ser), while the deep Indus gorge which terminates at one end of the section is subtended by the higher peak of Nanga Parbat. In apparent compensation for the Karakoram, which is the loftiest section of the ranges associated with the western half of the Himalayan chain, is the deep valley of the Upper Indus and Shigar from Skardu to Gilgit, here a longitudinal instead of a transverse excavation. In the eastern half of the chain, where gorges are frequent and deep, the summit line is nearly everywhere considerably above the 20,000-foot level. It would be rash to generalise from a single section, but Burrard & Hayden's section is enough to arouse a suspicion that extra uplift may compensate for extra excavation in its immediate vicinity.

Comparison with the tectonics of Burma.—In Burma the final uplift of the Shan plateau and of the Indo-Malayan mountain chain further south, as well as the more recent folding which affected the whole region, were parts of the Himalayan movement. To paraphrase much of what was written by La Touche, whose summary forms a well-laid foundation for any description of Burma tectonics, the geological history of the Shan States, so far as deposition under marine conditions is concerned, ended with the accumulation of the limestones of the Namyau series (Jurassic), the red beds of which ushered in continental conditions. So far, no marine Cretaceous rocks have been found on the Shan plateau and the subsequent history of the region is one of elevation above the sea and degradation. The nearest examples of marine deposition during this period are to be found in the Arakan Yoma and along the southern flanks of the Shillong plateau, where the work of filling up the Burmese and Himalayan foredeeps was actively in progress.[194]

Parts of the western margin of the Shan plateau, are so deeply dissected as to appear physiographically distinct from the tableland itself; this is well seen in the Southern Shan States, where Kalaw and Loi-an each lies on what has the appearance of an outlying ridge.[195] The main portion of the plateau is by no means a level

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[194] Mem. 39, pt. 2, 356 (1913).
[195] Rec. 67, pt. 2, 176 (1933).

plain, but has been compressed into several folded parallel N.-S. ranges, separated from each other by longitudinal valleys eroded at various elevations ; in fact, it has many of the features of an ordinary mountain area.

The nummulite-bearing strata found at great heights in the Himalaya have no parallel in the Shan States, a contrast which induced Suess to infer that the Burmese arc of folding preceded that of the Himalaya. For the most part, however, the great thrust movements, the one from the north and the other apparently from the east, must have proceeded simultaneously, and there is a considerable analogy between the final results attained in each case, though they are of very different orders of magnitude. " On the Burmese side we have the Shan plateau corresponding, but at a much lower elevation, with the Tibetan plateau, both of them being the elevated floors of an ancient ocean, now undergoing abrasion and reduction to a peneplain ". The outer edge of each plateau is bounded by a scarp or by an elevation having many of the features of a scarp and, " though it may seem almost absurd to compare the mighty chains of the Himalaya with the insignificant fringe of Archaean and Palaeozoic rocks that borders the Shan plateau, they certainly seem to bear some likeness to each other from a geological if not from a physical and spectacular point of view. Both are composed, speaking generally, of rocks older than those of the plateau beyond, and in both cases the main rivers, gathering on the uplands, break across the strike of the rocks through profound gorges. In each case the zone of older rocks is bounded by a great fault, or series of faults, forming the inner edge of the foredeep that separates them from the foreland of the continent beyond. In front of this again we have a zone of Tertiary strata, thrown into folds and greatly dislocated by faults, in the one case occupied by the Trtiary series of the Irrawaddy valley, and in the other by the Siwalik strata of the sub-Himalaya and by the *duns,* those wide valleys which separate the sub-Himilaya from the Siwalik ranges." La Touche compares the Arakan Yoma and its northward and southward prolongations to the Siwalik ranges, remarking that in this particular the order of magnitude is reversed, for in Burma these ranges attain a far greater altitude than those in northern India. There is, however, no very close equivalent to the Arakan Yoma in the Himalayan region, and it is unnecessary to press the analogy between India and Burma too far. The erratics described as occurring in part of the Yoma sequence (see p. 1607) indicate the presence in places of an autoclastic mélange similar to that found in some portions of the Lesser Himalaya and of the Tibetan zone but not in the Siwaliks, witnessing to fracture and thrusting of a severe type. In Burma the places of the Indus and Tsangpo valley trough is taken by the Salween valley to the east of the Shan States.

While the normal faulting in the Shan tableland bears no fixed relation to the general strike of the rocks, the thrusts and reversed faults are more or less parallel to the folding which produced them. If the Shan movement commenced a little earlier than the Himalayan,

it seems to have lasted till the Pleistocene, for a distinct tilt can be seen in the Pleistocene coal basins of the former region ; at the same time, there appear to be no cases of highly dipping post-Tertiary beds in Burma, from which it is to be inferred that the plicatory forces were smaller and less concentrated than they were in the Himalaya.

The massive character of the Plateau Limestone has had a marked effect on the response of the Shan rocks to the earth movement, compelling them to yield by fracture rather than by folding. The western edge of the Shan plateau itself is an almost unbroken line of jungle-covered N.-S. fault scarp, the result of an immense upthrust which in places is duplicated. These dislocations lie either along the foot of the plateau or under the Sittang alluvium or in the Tertiary strata adjoining. Movement along them and along other such faults may have persisted throughout the Tertiary era. As in the Himalaya, the earth movement in Burma probably varied considerably in intensity from time to time, and may have been slow and moderate at first. That it proceeded *pari passu* with deposition is seen where beds are overlapped by considerably younger stages ; in some cases such overlap is marked, as it is in the case of the Maw Gravels of Pakokku which are of Pleistocene or at the earliest very late Tertiary age and rest on the denuded upturned edges of the Palaeocene with a pronounced discordance.

From the edge of the Shan plateau to the alluvial plains of the Irrawaddy and the Sittang there is often an abrupt drop of more than 2,000 feet. On the plateau numerous lakes, such as the Inle and He-ho, formed in post-Tertiary times, just as they did in Tibet. As already noted, a considerable amount of the drainage of the Shan States is of an enclosed nature and has no visible outlet to the sea ; some of it, no doubt, finds its way thither beneath the Plateau Limestone by underground channels which join the major waterways. Southwards, in Karenni and Tenasserim, the plateau-like character of the Plateau Limestone becomes obscure and lost but, as a mountain belt, the formation can be recognised in Malaysia and the island of Banka.

As in the case of the Himalaya, thrusting is not confined to the edge of the mountain belt but occurs also within it. A good example of this is the great Lilu Thrust, which has a general N.-S. direction except where it passes through the Bawdwin lead and silver mines ; here it suffers a short temporary deflection and gives off a smaller branch.[196] This fracture, in the opinion of Coggin Brown, is the effect of the unyielding mass of old Chaung Magyi rocks a short distance to the west.

Proceeding eastwards from the Arakan Yoma, overfolding in the anticlines is seen to be first towards the east, the result being a steep easterly limb ; these conditions are followed by a zone of more or less symmetrical anticlines, which in their turn give place to anticlines showing overfolding towards the west where the folding has been

[196] Rec. 48, Pl. 7 (1917).

intense enough to display asymmetry. As respective examples we may cite the Yenangyat anticline of Pakokku, the Yenangyaung anticline of Magwe, and the Gwegyo anticline of Myingyan.

Omitting minor irregularities, the Arakan Yoma is an anticlinorium more or less overfolded towards the west or northwest, *i.e.*, with a predominant dip to the east or southeast. At the commencement of the Tertiary era it formed a long narrow island or peninsula jutting southwards and separating the Pegu gulf on the east from the Assam gulf on the west. Southwards it stretched through the Andaman and Nicobar islands; at present the range ends in Cape Negrais, but between the latter and the Andamans are reefs and a few detached islands. Further south, its line continues through the Barissan range of Sumatra into Java.[197]

As a ridge of land the Arakan Yoma seems to have been initiated at the beginning of the Tertiary era, for there is a more or less constant conglomerate at the base of the Palaeocene of this area, indicating a coast-line along what is now the eastern foot of the Yoma.[198] That this ridge could not have existed as an efficient land barrier much before the beginning of the Tertiary era is shown by the fact that the Cretaceous beds found in the second defile of the Irrawaddy are very similar to those of Assam and were probably more or less continuous therewith.[199] The Cretaceous of the Yoma with its extremely scanty fauna is marine in character.

The long and narrow Pegu gulf occupied an area, the continuous subsidence of which accompanied the continued rising of the Yoma geo-anticlinorium. Keeping pace with these movements, there was a progressive retreat of the sea southwards, fluviatile sedimentation and deltaic deposition shifting continuously in the same direction. Clegg calls attention to the progressive way in which the various fluviatile sandstones stretch further and further southwards as we rise in the stratigraphical scale, attaining a maximum thickness and petering out *en echelon*.[200] The Tilin sandstones, for example, die out at latitude 20° 15′, the Pondaung sandstones at 20°, and the Shwezetaw sandstones still further south; sandstones corresponding to the Singu stage of the Pegu attain their maximum development at latitude 19° 15′ and appear to vanish before the latitude of Prome is reached, while the Prome sandstones reach their maximum thickness between Kama and Prome.

In Lower Eocene times the sea reached far to the north and covered the greater part of the Pakokku district. In Upper Eocene times it began to retreat from areas such as Myaing in the north of that district. In the Pegu period, according to Cotter, deltaic conditions prevailed over the major portion of Pakokku, and beds of that age can be recognised in the northwest quarter of the Minbu

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[197] Tobler. Tijdschr. Vanhet Koninkl. nederl. aardr. genootsch., Jaarg 1906. p. 292; Rec. 51, pt. 3, 302 (1921).

[198] Cotler, J. A. S. B., New Ser., 14, 412 (1918); Pascoe. Rec. 42, 261 (1912).

[199] Rec. 72, pt. 1, 64 (1937).

[200] Mem. 72, pt. 2, 170 (1938).

district; red earth beds are numerous though discontinuous throughout the Pagu of north Minbu and Pakokku. In early Irrawadian times estuarine conditions retreated to Thayetmyo and before the end of that period the whole basin was one of sub-aerial fresh-water deposition. For the greater part of the Tertiary era the gulf seems to have occupied only the western part of the area between the Shan plateau and the Arakan Yoma. No Tertiary rocks older than Miocene have been discovered east of a line of vulcanicity joining the Lower Chindwin volcanoes with Mount Popa, and its continuation southwards along the eastern edge of the Yenangyaung basin; to the east of this line the strata are all of a very shallow-water facies, and fossils are rare.

The general subsidence seems to have ceased to affect Upper Burma at the close of the Tertiary, for the Plateau Gravel shows signs of having been elevated. The depth of water in the Pegu gulf naturally varied from time to time but, according to Cotter never exceeded 200 fathoms, judging from the character of its marine fossils, in spite of the fact that some forty or fifty thousand feet of sediment, marine and fluviatile, accumulated in this sinking area. As examples of comparatively deeper-water sediments may be instanced the Yaw Shales or the Padaung Clays; the Pondaung and Shwezetaw sandstones, on the other hand, represent a shallower-water type of deposition.

The floor of the Pegu gulf suffered a certain amount of corrugation which accompanied the general subsidence of the synclinorium. The largest and broadest of these minor folds was the anticline of the Pegu Yoma, which is unquestionably younger than the Arakan Yoma. It could scarcely have taken shape before the later half of the Tertiary and probably did not undergo its final elevation till after the Irrawadian period. Clegg concludes that deposition began earlier in the western half of the Tertiary basin than it did in the eastern half, for the latter appears to be devoid of Oligocene or older Tertiary rocks[201] and may have formed land during these earlier periods. Post-Oligocene folding seems to have caused an invasion of the sea over the eastern area, which thence forward sustained the more continuous deposition. Clegg remarks that, east of the Popa volcanic line, which is approximately a northward continuation of the crest of the Pegu Yoma, the oilfields and the thick deposits of ferruginous conglomerate so characteristic of the western area are not found, and the boundary between the Pegu and Irrawadian formations is even more arbitrary than it is in the west; in eastern Myingyan, in fact, it has been necessary to introduce a series of passage beds between the two series to facilitate mapping.

The smaller scale corrugation of the Pegu gulf floor, which may well have continued throughout the whole Tertiary era, seems to have been responsible for local erosion and unconformity along N.-S. lines close to the crests of several of the anticlines, for the marked disparity in thickness of strata on each side of the axes does not

[201] Rec. 72, pt. 1, 64 (1936).

seem to be entirely a matter of fold-faulting, though accompanied by such dislocations.

If we except local uncoformities of no great magnitude and some of the examples of overlap, there is no widespread discordance in dip from the base of the Palaeocene up to the base of the Irrawadian, and in fact in a large number of sections no angular unconformity is to be discerned between the top of the Pegu and the base of the Irrawadian. Sedimentation has been continuous throughout in some portion or other of the gulf.[202] In some places the Yaw beds of the Eocene pass up into the Pegu, just as the latter sometimes appear to do into the Irrawadian.

From the evidence of numerous and frequent small earthquakes, such as those of September, 1927, December of the same year, January, 1929, May, 1930, July, 1930, December, 1930, and others, the Shan movement has not yet ceased. The epicentres of the above disturbances lie along a line parallel to the eastern boundary of the Tertiaries, close to the foot of the well marked ridge containing the peaks of Pondaung, Khengdan, Myayabengkyo and others, west of Sittang plain. This line, almost certainly connected with a line of fracture is not the same as the Shan plateau scarp fault which lies further to the east on the other side of the Sittang valley.[203]

The occurrence along portions of the foot of the Shan plateau of granite intrusions believed to be of late Mesozoic age predicates a thick covering of Mesozoic rocks at the time of intrusion ; these must have been denuded away before the end of Irrawadian times since the granites are overlapped by the Irrawadian sediments.[204]

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[202] Cotter, Rec. 44, pt. 3, 165 (1914).
[203] Coggin Brown, Rec. 65, pt. 2, 268 (1931).
[204] Rec. 72, pt. 1, 64 (1937).

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CORRIGENDA.

A Manual of the Geology of India and Burma, Vol. III,
Third Edition, E. H. Pascoe.

Page No.	Paragraph No.	Line No.	For	Read
1346	1	22	laterstisation . . .	lateritisation
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1352	1	1	sandstones . . .	sandstone
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1377	1	14	*Limnaeda* . . .	*Lymnaea*
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1416	3	1	peridotties . . .	peridotites
1416	3	2	Chibber	Chhibber
1419	1	26	wager	Wager

Page No.	Paragraph No.	Line No.	For	Read
1419	last	last	instrusions . . .	intrusions
1424	2	18	serictic	serioitic
1425	last	12	Chanda . .	Chandra
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1471	last	5	ant	and
1472	——	2	PALAEOCEN . .	PALAEOCENE
1472	Contents	21	Hundas . . .	Hundes
1472	Contents	26	Coromondal . . .	Coromandel
1472	Contents	26	contribution . . .	continuation
1472	Contents	27	EOCENEII . . .	EOCENE
1473	3	8	diposition . . .	deposition
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1483	——	32	*Cyclol tes* . . .	*Cyclolites*
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1489	——	7/8	*Anplogladius* . . .	*Amplogladius*
1489	——	11	*Rostellarin* . . .	*Rostellaria*
1489	——	11	*Terebelopsis* . . .	*Terebellopsis*

Page No.	Paragraph No.	Line No.	For	Read
1489	2	3	fosil	fossil
1490	2	1	Limestoe . . .	Limestone
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1491	3	1	pot	spot
1494	footnote	7	Casamann . . .	Cossmann
1495	1	14	*leymieric* . . .	*leymric*
1499	—	3	Aligocene . . .	Oligocene
1499	—	21	*Cybricardia* . . .	*Cypricardia*
1499	—	40	*Glubulus*	*Globulus*
1511	footnote	12	Nutall	Nuttall
1515	footnote	1	*Numulites* . . .	*Nummulites*
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1548	—	21	*nuttali*	*nuttalli*
1548	—	28	*subsala*	*subvalsa*
1548	—	last	Eymar	Eymer

Page No.	Paragraph No.	Line No.	For	Read
1549	last	7	corwded	crowded
1550	1	6	*Lamina*	*Lamna*
1550	4	8	Eymar	Eymer
1553	1	29	*viuesneli*	*viquesneli*
1553	2	7	Maris	Marls
1558	footnote	2	*nutalli*	*nuttalli*
1560	last	24/25/26	pockets and thin seams of crushed, 4. Carbonaceous and pyritous schistose shales , graphitic coal; ironstone shales	4. Carbonaceous and pyritous schistose shales ; pockets and thin seams of crushed, graphitic coal; ironstone shales
1561	last	last	0·30 feet . . .	0—30 feet
1563	footnote	last	Lydekkar . . .	Lydekker
1564	4	last	Hundas	Hundes
1565	2	14	alive	olive
1568	footnote	4	d' Archaic . . .	d' Archiac
1569	1	6	*roualti*	*rouaulti*
1569	2	2	rocks	rock
1572	footnote	4	Pal. Ind., 24 No. 1, 69 (1987)	Pal. Ind., 24 No. 1, 69 (1937)
1572	footnote	4	Pal. Ind. 24, No. 1, 71 (1987)	Pal. Ind., 24 No. 1, 71 (1937)
1573	footnote	5	Delheldia . . .	Delheidia
1574	—	44	OCTRACODA . .	OSTRACODA
1574	footnote	1	a laki from . . .	a Laki form from
1575	1	6	*Sponhylus* . . .	*Spondylus*
1575	1	30	*noetlinoi* Cossom. & P. .	*noetlingi* Cossm. & P.
1575	1	31	*fusoidasi* . . .	*fusoides*
1577	4	4	tributory . . .	tributary
1581	4	12/13	in all probability Dr. Spenglar has identified	in all probability to Evan's Kopili Stage. From beds of the same age at Therriaghat Dr. Spengler has identified.
1583	—	7	ame	name
1583	—	7	origially . . .	originally

Page No.	Paragraph No.	Line No.	For	Read
1583	footnote	13	Spendler . . .	Spengler
1583	footnote	17	Cinfirmed . . .	confirmed
1584	—	9	*roualtid'* Arch. . .	*rouaulti* d' Arch.
1584	—	9	*Natica roualti* . . .	*Natica rouaulti*
1585	footnote	3	bed	beds
1592	2	1	eruption	eruptions
1598	2	12	bas	base
1598	footnote	1	Chibber	Chhibber
1599	4	6	general	genera
1599	4	21	Umta	Uinta
1600	—	1	ANTHRACOTHERÍDAE	ANTHRACOTHERIIDAE
1600	—	14	FRAGULIDAE . .	TRAGULIDAE
1604	—	7	Bottg.	Boettg.
1609	1	14	quatzitic . . .	quartzitic
1614	footnote	1	fase	fase.
1618	last	last	clays . . .	clays.
1622	last	last	*intermedi* . . .	*intermedius*
1622	footnote	4	megalosphesic . . .	megalospheric
1625	—	11	*Vred.* . . .	Vred.
1626	—	11	*d.Orb.*	*d'Orb.*
1626	—	38	*Sacco*	Sacco
1626	—	47	*Tarritella* . . .	*Turritella*
1639	—	14	Fatehganj . . .	Fatehjang
1642	2	3	mantelli")[7] W.L.F. Nuttall	mantelli")[7]
1642	4	5	brevis	*brevis*
1643	8	11	*hemisphaaericus* . .	*hemisphaericus*
1644	2	3	*larkanensis* . . .	*larkhanaensis*
1644	2	41	*Omphaloclathum* . .	*Omphaloclathrum*
1645	2	2	*Conns* . . .	*Conus*
1648	footnote	4	*Haime*	Haime
1650	3	4	it .	of

Page No.	Paragraph No.	Line No.	For	Read
1658	—	9	*F. Cooper* . . .	F. Cooper
1658	footnote	2	Ser. 8, 16, 12 . . .	Ser. 8, 12
1665	1	1	Khain-i-Murat . .	Khair-i-Murat
1667	1	8	Jang	jang
1667	footnote	last	Flestmantel . . .	Fiestmantel
1670	—	19	*Garialis*	*Gharialis*
1671	footnote	2	Kasaull	Kasauli
1672	1	9/10	Dagshahi . . .	Dagshai
1678	3	5	*protoreevesi* . . .	*protoreeversii*
1681	2	32	*Tritonirdea* . . .	*Tritonidea*
1682	—	39	*Myliobatis* . . .	*Myliobates*
1683	3	5	*vataviana* . . .	*bataviana*
1684	3	12	tow	two
1687	3	14	V.	W.
1689	4	11	Oligocane . . .	Oligocene
1689	4	last	Shwezettaw . . .	Shwezetaw
1692	3	3	Sinkik	sinking
1693	3	3	inliers	miles
1699	—	36	borders	borders of
1700	7	1	CASTROPODA . .	GASTROPODA
1700	7	last	*Noetl*	Noetl.
1701	5	8	*prootophilippinarum* .	*protophilippinarum*
1702	1	last	Nietl.	Noetl.
1703	1	1	Myliobates . . .	*Myliobates*
1703	1	4	*Oxirhina* . . .	*Oxyrhina*
1703	1	4	*spala nzanii* . . .	*spallanzanii*
1703	5	2	Dung.	Duno.
1704	3	1	*spalanzanii* . . .	*spallanzanii*
1706	3	4	*protophillipinarum* . .	*protophilippinarum*
1708	4	1	*Noetl.*	Noetl.
1708	4	6	*protophillipinarum* . .	*protophilippinarum*
1709	3	1	AOTINOZOA . . .	ACTINOZOA

Page No.	Paragraph No.	Line No.	For	Read
1709	4	2	*pritophilippinarum* . .	*protophilippinarum*
1709	6	1	FISH OTOLITHS . . *Python molurus* Linne'.	FISH OTOLITHS OPHIDIA *Python molurus* Linne'.
1710	3	9	Dunk.	Dunc.
1711	—	13	tasmanicus, . . .	*tasmanicus*,
1711	—	17	*Noetl.*	Noetl.
1711	—	28	*Cott.*, ...	Cott.,
1712	—	44	*Balanus* (*chirona*) *birmanicus*,	*Balanus* (*chirona*) *birmanicus*, Withers.
1714	3	2	*Cidarie* . . .	*Cidaris*
1715	—	last	noetlingi . . .	*noetlingi*
1716	—	4	*bicinta*	*bicincta*
1716	—	21	cclosely	closely
1717	—	25	*gransi*	*granti*
1722	—	last	Withere	Withers
1725	4	15	Peku	Pegu
1726	1	last	Akautang . . .	Akauktang
1726	2	last	bds	beds
1726	footnote	last	Vredenburk . . .	Vredenburg
1727	2	last	pentiful	plentiful
1730	2	4	consolidated . . .	of more co-
1730	footnote	last	E. Noetling . . .	F. Noetling
1732	5	10	*Indica*	*indica*
1735	1	12	gypseferous . . .	gypsiferous
1735	3	7	Shah	Shan
1739	footnote	1/2	repirted	reported
1740	—	16	pilg.	Pilg.
1740	—	last	Plig.	Pilg.
1742	2	15	*Brahma*-	*Brama*-
1742	6	2	*Palaeochoerus* . . .	*Palaeochaerus*
1743	1	1	*Palaeochoerus* . . .	*Palaeochaerus*
1744	1	18	auctt.	var.

Page No.	Paragraph No.	Line No.	For	Read
1745	--	7	*basal*	basal
1745	—	9	G. w.	Gw.
1745	—	44	*Cytherae*	*Cytherea*
1745	—	49	*Chemm.*	Chemn.
1746	—	26	from	form
1747	—	17	Ww.	Gw.
1750	3	4	earthly	earthy
1756	4	15	*Amphicyon* . . .	*Amphicyon*
1765	2	3	*Listridon* . . .	*Listriodon*
1765	2	18	*Trilochodon* . . .	*Trilophodon*
1767	—	18	*Bramapithecus* . .	*Brahmapithecus*
1767	—	19	*Bramapithecus* . .	*Brahmapithecus*
1767	—	27	84 *Paraulacodus* . . .	*Paraulacodus*
1767	—	36	*Trilophodo* . . .	*Trilophodon*
1768	—	26	Torrisodactyla . .	Perrisodactyla
1768	—	45	pentapotamioe . .	pentapotamiae
1768	—	46	*Lyd.*	Lyd.
1768	—	47	*Palaeryx* . . .	*Palaeoryx*
1769	1	8	*Dicoryphochoeru* . .	*Dicoryphochoerus*
1769	1	21	*Sivoreas*	*Sivaceras*
1770	5	5	*Palaeochoerus* . . .	*Palaeochaerus*
1770	footnote	4	87	97
1774	—	11	*pentapotamide* . . .	*pentapotamiae*
1774	—	28	*Lyceana* cf. *macrosoma* .	*Lyceona* cf. *macrostoma*
1776	—	7	*paloenaicum* . . .	*palaeindicum*
1777	—	18	*Listridon* . . .	*Listriodon*
1777	—	36	*Hippopotamns* . . .	*Hippopotamus*
1777	—	44	*duverniyi* . . .	*duvernoyi*
1777	—	47	*punjobensis Pilg.* . .	*Punjabensis* Pilg.
1783	1	6	form	from
1787	1	3	ad	and
1787	1	6	*Tetracondon* . . .	*Tetraconodon*

Page No.	Paragraph No.	Line No.	For	Read
1788	1	8/9	*Tetracodon*	*Tetraconodon*
1789	2	10	*stegodon*	*stegodon* is
1780	3	7	*Antelopine*	*Antilopine*
1795	—	26	Pig.	Pilg.
1795	—	27	*Dorcubane*	*Dorcabune*
1798	—	46/47	*Felistigris*	*Felis tigris*
1799	—	12	*platycebhalus*	*platycephalus*
1799	—	18	*Equus* caballus.	*Equus calallus*
1799	—	31	*Tetrocondon*	*Tetraconodon*
1800	footnote	2	176	178
1810	—	13	*varrelli*	*yarrelli*
1810	—	31	*Chira*	*Chitra*
1810	—	43	LICERTILIA	LACERTILIA
1810	—	46	*Molurus*	*molurus*
1813	1	5	*Miocene forms*	Miocene forms
1813	2	2	pontian	Pontian
1813	2	3	alone	along
1813	3	10	Carvidae	Cervidae
1813	3	13	Oioceros	*Onioceros*
1813	3	13	India	Indian
1814	4	1	anthrapoid	anthropoid
1815	3	5	lower	Lower
1816	3	20	*Strepsiporitax*	*Strepsiportax*
1816	3	25	abiquitous	ubiquitous
1817	1	7	Protragelaphus	*Protragelaphus*
1818	1	22	Pleistoncene	Pleistocene
1820	4	1	thiner	thinner
1820	4	7	Lower	lower
1826	—	8	vimineus),"	vimineus"),
1832	1	9	Or	or
1835	—	23	*Garialis*	*Gharialis*
1835	—	25	*Clift*	*Cliftii*

Page No.	Paragraph No.	Line No.	For	Read
1835	—	34	*Mehycopotamus*	*Merycopotamus*
1835	—	35	*irravaticus*	*iravaticus*
1836	1	1	*irravaticus*	*iravaticus*
1836	2	2	Crawford	Crawfurd
1836	5	5	*Rhinocers*	*Rhinoceros*
1836	6	5	*irravaticus*	*iravaticus*
1837	4	9	*C.*	*G.*
1838	3	10	mbcd	bcd
1839	2	24	*antiquus,*	*antiquus*
1839	2	25	wascular	vascular
1840	2	11	show	shows
1841	1	3	drift wood	driftwood
1841	3	2	Sew.	Sow.
1841	3	2	measures	Measures
1848	3	6	thinck	thick
1850	last	last	mines	Mines
1852	footnote	3	Chibber	Chhibber
1855	footnote	1	Chibber	Chhibber
1856	7	3	Natalabo	Natlabo
1861	5	2	traverse	traverses
1862	2	11	layes	layers
1863	1	5	andestitic	andesitic
1863	1	16	of his hills	of hills
1870	1	2/3	*lit-per-lit*	*lit-par-lit*
1874	2	12	anacite	analcite
1875	footnote	5	Mokpalin	Mohpalin
1875	footnote	10	on	of
1876	1	1	Ieng-yueh	Teng- yueh
1878	1	2	Porebandar	Porbandar
1878	1	6	Evdience	Evidence
1878	1	9	Littorol	Littoral
1878	1	19	plungs	pungs

Page No.	Paragraph No.	Line No.	For	Read
1883	last	last	adentate	edentate
1886	—	19	Rut	Rüt
1886	—	19	*nugai*	*nilgai*
1886	—	31	Elephas antiquus(namadicus)	*Elephas antiquus*(*namadicus*)
1890	footnote	2	30	38
1895	4	11	Blandford	Blanford
1900	footnote	last	60	68
1901	footnote	last	69	71
1902	1	21	Born.	Bron.
1904	3	21	there into	thereinto
1914	footnote	3	Blandford	Blanford
1916	footnote	1	171	111
1927	3	22	slit	silt
1928	2	4	bluff	buff
1928	3	last	scrap	scarp
1948	footnote	5	263	203
1949	footnote	2	265	205
1953	footnote	3	Dubley	Dudley
1969	2	9	Low	low
1974	3	1	laterite	Laterite
1975	2	27	form soon after the emergence of this ancient peneplain, it might.	conceivably have done much to preserve plateau conditions; this of
1975	2	28	Courseis contrary to the idea that true laterite is peculiarly and almost	
1976	4	1	laterite	Laterite
1979	2	21	lateritisation	Laterite
1982	3	1	bengalensis	*bengalensis*
1982	4	1	*globoso*	*globosa*
2005	last	last	soil	soils
2010	3	1	interected	intersected
2015	1	32	general	genera
2017	1	9	Himal yan	Himalayan

Page No.	Paragraph No.	Line No.	For	Read
2022	2	12	Chgumbi . . .	Chumbi
2034	2	22	Murree	Murree
2036	2	25	sytems	systems
2047	1	11	Sabathu	Subathu
2052	last	last	synclinoriam . . .	synclinorium
2065	—	—	PLANTS . . .	PLAINS
2065	—	15	*nappe*	*Nappe*
2065	—	21	*thrusts*	*Thrusts*
2065	—	26	Jumma	Jumna
2066	last	11	elevations . . .	elevation
2068	footnote	2	H.	*Pelete*
2069	1	4	93	92
2069	1	8	92	93
2070	—	1	Elippi	Fillipi
2072	3	11	anomally . . .	anomaly
2074	2	13	Nagri	Ngari
2077	2	19	Satt	salty
2077	3	last	Nagri	Ngari
2100	1	29	mandi	Mandi
2102	1	5	crowed	crowded
2102	last	last	origanate . . .	originate
2104	last	16	form	formed
2105	2	7	midly	mildly
2115	footnote	3	Cotler	Cotter

MGIPC—S5—1 Mines/59—10-3-64—1,650.